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AN INVESTIGATION OF DESCRIBING FUNCTION DEVELOPMENT

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AN INVESTIGATION OF DESCRIBING FUNCTION DEVELOPMENT

by

Jerry Michael Loveless
Lieutenant, United States Navy
B.S. United States Naval Academy, 1959

[redacted]

Submitted in partial fulfillment
for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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May 1966

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ABSTRACT

Since Kochenburger presented the describing function numerous attempts have been made to improve and/or simplify the methods of studying nonlinearities in servo-mechanisms. This paper reviews some of the most common methods of describing function development.

The describing function has been used primarily for stability analysis on the Nichols, polar, and Nyquist plots. This paper shows the use of the real and imaginary components of the describing function on the parameter plane. In addition a generalized digital computer program is developed for generating describing function data for a large class of nonlinearities. Data is computed and tabulated for a number of common nonlinearities, and these tables are included as an appendix.

The writer wishes to express his appreciation for the assistance and guidance given him in this investigation by Dr. George J. Thaler of the U.S. Naval Postgraduate School.

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AN INVESTIGATION OF DESCRIBING FUNCTION DEVELOPMENT

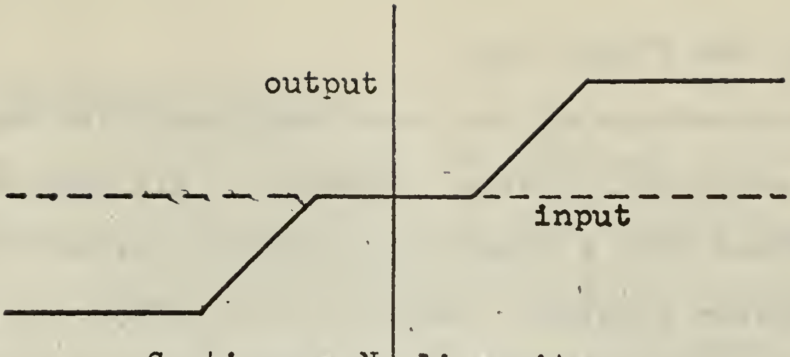
1. INTRODUCTION

The use of linear theory in the analysis of servomechanisms can be justified if the nonlinearities can be neglected, and if all components in the system perform in an ideal manner. No real system performs ideally however, and a point is reached where the nonlinearities can no longer be neglected. Kochenburger[11] first introduced the describing function which is a method of representing a nonlinearity by an approximate equivalent linear transfer function. The describing function is defined as a magnitude and angle; the magnitude being the ratio of the output wave to the input wave, and the phase angle being the difference between the phases of the output and input waves. Kochenburger's definition was based on applying a sinusoidal input to the nonlinearity under study. The output will, in general, be periodic with the same period as the input, but will contain many harmonics not present in the input. If the control system being studied acts as a low pass filter then most of the higher harmonics will be filtered out and only the fundamental will remain. The transfer function for the nonlinearity will be simply a gain factor (magnitude) with possibly some phase shift. A phase shift is introduced whenever the graph of the nonlinear element shows a closed loop indicating hysteresis or backlash.

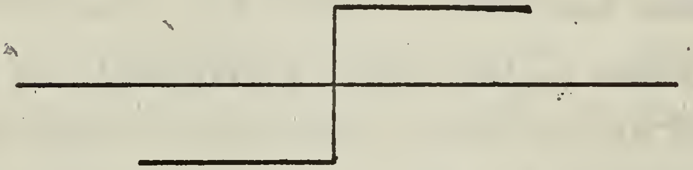
Since Kochenburger, many other types of describing functions have been developed. The reasons for the new developments have included attempts at increased accuracy, simplification of computation, and methods of handling nonsinusoidal inputs. Kochenburger's method has gained wide popularity, and is by far the most common one in use today for general cases. In certain special cases, however, other types of describing functions are superior to Kochenburger's. Several of the more common methods of describing function development are described in the following sections. They include:

a. Conventional (Kochenburger's Fourier fundamental method)
b. Minimum Average Error
c. Minimum Absolute Value Error
d. Princes Equivalent Gain
e. Ogata's Method
f. New Root Mean Square (RMS)
g. Corrected Conventional
h. Elliptic
i. Exponential
j. Dual Input

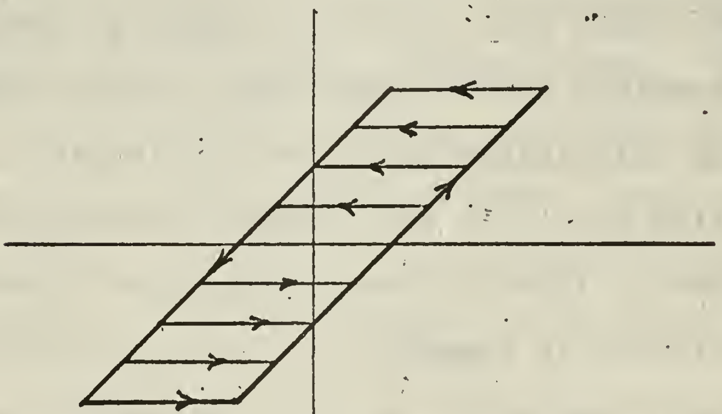
Nonlinearities may be classified in several ways. A continuous nonlinearity is one which has only one value of output for a particular input magnitude. A discontinuous nonlinearity, then, would be one such as a relay, which has two possible values for the same input. This latter case is also known as a fast nonlinearity since the output changes rapidly with respect to the time constants of the overall



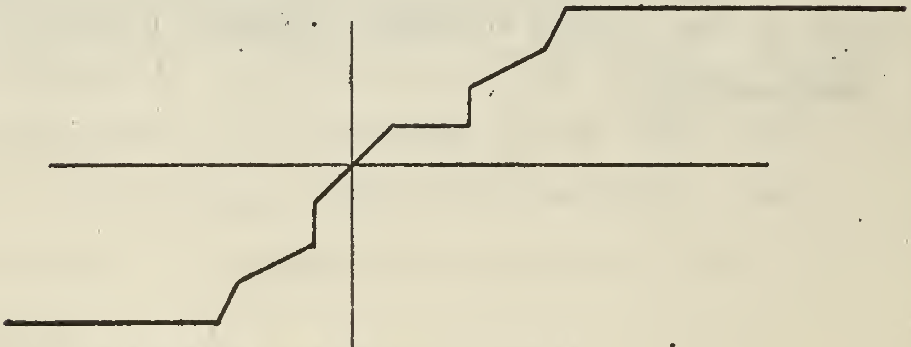
Continuous Nonlinearity



Discontinuous Nonlinearity



Multivalued or Memory Nonlinearity



Single Valued Nonlinearity

TYPES OF NONLINEARITIES
Figure 1-1

system. See Figure 1-1.

Combinations of the above nonlinearities may be found in any particular system. Hopefully, all nonlinearities can be combined into a single nonlinearity, greatly reducing the analysis problem. However, it is often not possible to combine nonlinearities. For example, if two nonlinearities are separated by an element having a transfer function which is frequency sensitive or which has a gain not equal to one, then the input to the second nonlinearity is not equal to the output of the first, and the two cannot be combined directly. Thaler[1] gives an extensive discussion of manipulation of block diagrams which contain nonlinear elements.

Even when nonlinearities cannot be combined it is still possible to use describing function theory, but the labor of calculation increases considerably. A case of a saturating amplifier and friction controlled backlash separated by linear elements which are frequency dependent is considered in Appendix II. The major problems which occur are first, the inputs to both nonlinearities become frequency dependent, and second, the output of the first nonlinearity is modified in amplitude (as a function of frequency and the gain of the linear elements) before it enters the second nonlinearity.

2. GENERALIZED DESCRIBING FUNCTION

If two or more nonlinearities are combined, a new describing function must be derived for the combination. For example, the describing function for deadzone and saturation is not simply the sum of the two individual describing functions. It then appears desirable to have a single describing function which is generalized to handle any nonlinearity or combination of nonlinearities. Sridhar[16] did this for a large number of common nonlinearities, basing his development on the Conventional (Fourier fundamental) Describing Function. Using Sridhar's development a computer program was developed to compute data for any describing function which falls under Sridhar's classification. The program uses Fortran 60 compiler, and was developed using the Control Data Corporation 1604 digital computer. This program along with instructions for using it is included in Appendix III.

Sridhar's technique was to consider a complicated nonlinearity (shown in Fig. 2-1) and write the describing function. Then, when considering a simpler nonlinearity which is similar to the original, certain terms in the general describing function automatically cancel out. After integrating to obtain the coefficients of the Fourier fundamental of the output wave, and dividing by the input wave (see Section 3 -- Conventional Describing Function), the equations for the real and imaginary components of the output wave become:

$$\mathrm{Im(GD)} = \frac{n_1}{\pi E}\Big[\frac{E}{2}(\cos 2\theta_1 + \cos 2\theta_3 - \cos 2\theta_4 - \cos 2\theta_5)$$

$$+ 2a(\sin\theta_1 - \sin\theta_5) + 2d(\sin\theta_3 - \sin\theta_4)\Big]$$

$$+ \frac{n_2}{\pi E}\Big[\frac{E}{2}(-\cos 2\theta_3 + \cos 2\theta_5)$$

$$+ 2k_2(\sin\theta_5 - \sin\theta_3)\Big]$$

$$\mathrm{Re(GD)} = \frac{n_1}{\pi E}\Big[E(-\theta + 2\theta_2 + \theta_3 - \theta_4 - \theta_5) + \frac{E}{2}(\sin 2\theta_1$$

$$- 2\sin 2\theta_2 - \sin 2\theta_3 + \sin 2\theta_4 + \sin 2\theta_5)$$

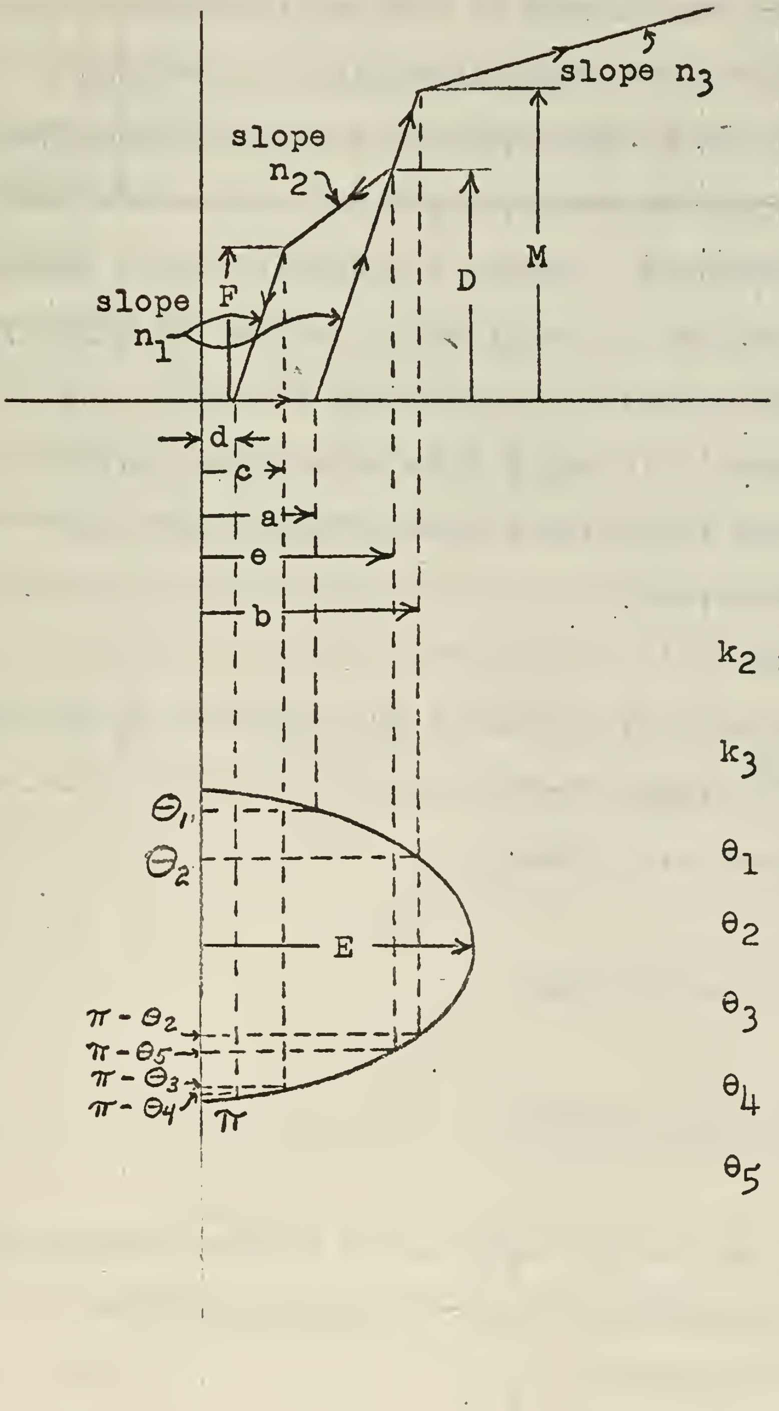
$$+ 2a(-\cos\theta_1 + 2\cos\theta_2 - \cos\theta_5) + 2d(\cos\theta_3 - \cos\theta_4)\Big]$$

$$- \frac{n_2}{\pi E}\Big[E(\theta_5 - \theta_3) + \frac{E}{2}(\sin 2\theta_3 - \sin 2\theta_5)$$

$$+ 2k_2(\cos\theta_5 - \cos\theta_3)\Big] - \frac{n_3}{\pi E}\Big[E(\pi - 2\theta_2)$$

$$+ E\sin 2\theta_2 - 4k_3\cos\theta_2\Big]$$

$$\mathrm{GD} = \sqrt{\mathrm{Re}^2 - \mathrm{Im}^2} \quad \angle \tan^{-1}\frac{\mathrm{Im}}{\mathrm{Re}}$$



$$k_2 = c - \frac{F}{n_2}$$

$$k_3 = b - \frac{M}{n_3}$$

$$\theta_1 = \sin^{-1} \frac{a}{E}$$

$$\theta_2 = \sin^{-1} \frac{b}{E}$$

$$\theta_3 = \sin^{-1} \frac{c}{E}$$

$$\theta_4 = \sin^{-1} \frac{d}{E}$$

$$\theta_5 = \sin^{-1} \frac{e}{E}$$

Figure 2-1 Generalized Describing Function

3. CONVENTIONAL DESCRIBING FUNCTION (FOURIER FUNDAMENTAL)

The advantages of one type of describing function over another depends upon the type of system being considered, the accuracy required and the amount of time available for analysis. In the study of servo-mechanisms using describing function theory the use of conventional describing function, developed independently by Kochenburger and others [12,13,14] has become widely accepted. Except for special cases where a high degree of accuracy is required or, where the input is nonsinusoidal, the conventional describing function is a suitable approximation. In using this method the output wave is expanded into a Fourier series of which only the fundamental is considered.

$$\text{INPUT} = E\sin wt$$

$$\text{OUTPUT } o(t) = \frac{A_o}{2} + A_1 \cos wt + B_1 \sin wt + A_2 \cos 2wt + B_2 \sin 2wt + \ldots\ldots$$

where the coefficients are given by

$$A_n = \frac{2}{\pi}\int_0^{\pi} O(t) \cos (nwt) dwt$$

$$B_n = \frac{2}{\pi}\int_0^{\pi} O(t) \sin (nwt) dwt$$

By definition the output wave has no average component and thus $\frac{A_o}{2} = 0$. Considering only the fundamental the describing function becomes:

$$N = \frac{\text{output fundamental}}{\text{input}}$$

$$N = \frac{\sqrt{A_1^2 + B_1^2}}{E \angle 0^\circ} \angle \mathrm{Tan}^{-1} (B_1/A_1)$$

As shown in Figure 3-1b the general technique is to cut the loop at the input to the nonlinearity. Since the describing function is defined such that the input is sinusoidal, this implies that the output of the linear element is also sinusoidal and of the same frequency. In fact when the loop is closed again the two signals are identical. This assumes that all higher harmonics are completely filtered out since $v_1 = v_3$ when the loop is closed. This assumption naturally limits the field of accurate application of this analysis. However, in servomechanisms and control systems the higher frequencies are greatly attenuated. If interfering signals and subharmonics are negligible then the approximation becomes valid.

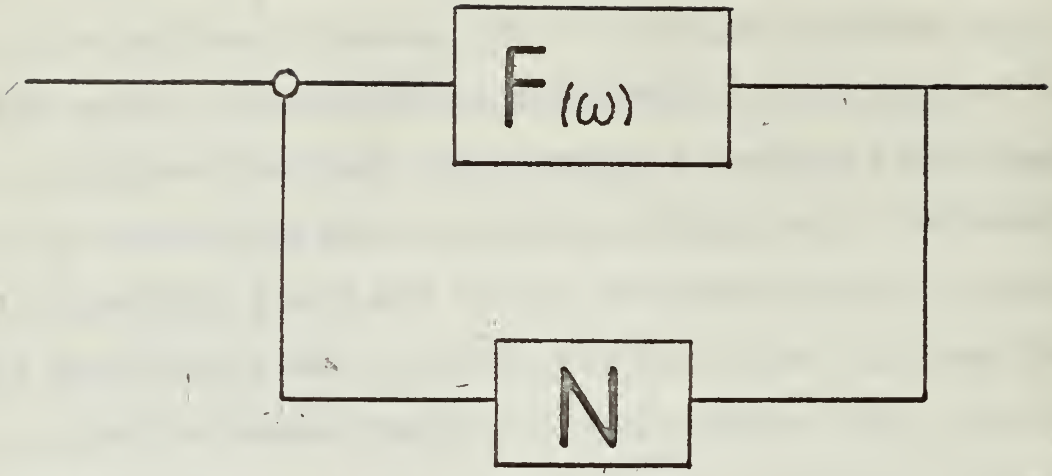
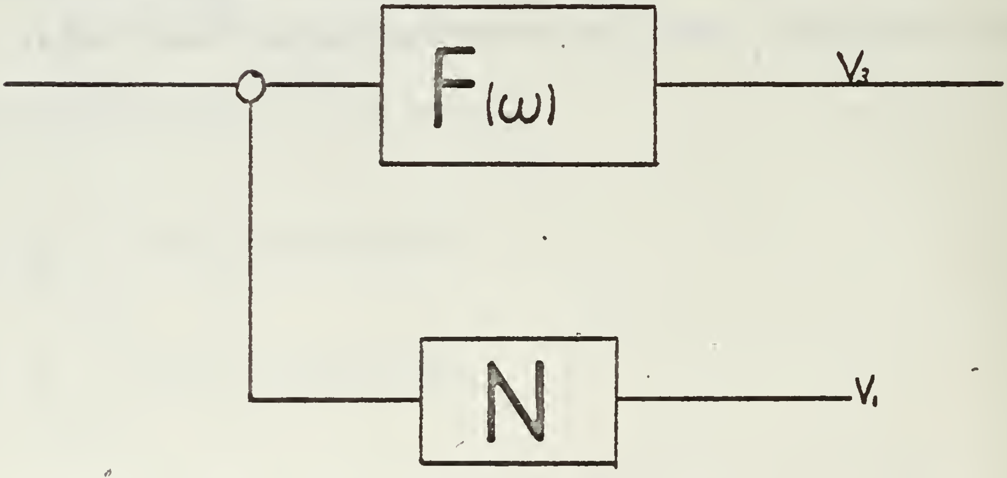


Figure 3-1a



Typical Block Diagram of System Containing Nonlinear Element

Figure 3-1b

4. MINIMUM AVERAGE ERROR DESCRIBING FUNCTION

Developed by Gibson[6] the Minimum Average Error Describing Function, as its name suggests obtains the magnitude of the sine wave required to minimize the average error. This is accomplished by minimizing the area of the equivalent output sine wave and the area of the actual output wave.

Example:

Consider a perfect relay, shown in Fig. 4-1. The conventional describing function is $GD = \frac{4M}{\pi E}$

In this case the average error is the difference between the area under one half cycle of the equivalent sine wave and the area of the actual output square wave.

$$\text{ERROR} = \int_0^{\pi} M d\theta - \int_0^{\pi} D \sin\theta \, d\theta$$

$$= \int_0^{\pi} (M - D \sin\theta) \, d\theta = \pi M - 2D$$

In this case it is possible to reduce the error to zero giving

$$D = \pi \frac{M}{2}$$

Dividing by the input the describing function then becomes

$$GD = \frac{D}{E} = \frac{\pi M}{2E}$$

which is a factor 1.23 $\left(\frac{(\pi^2)}{8}\right)$ larger than the conventional describing function.

This describing function has the disadvantage of introducing large negative errors to compensate for large positive errors, and of course, one is as bad as the other. A different approach to describing function development which compensates for this disadvantage is to minimize the absolute magnitude of the average error.

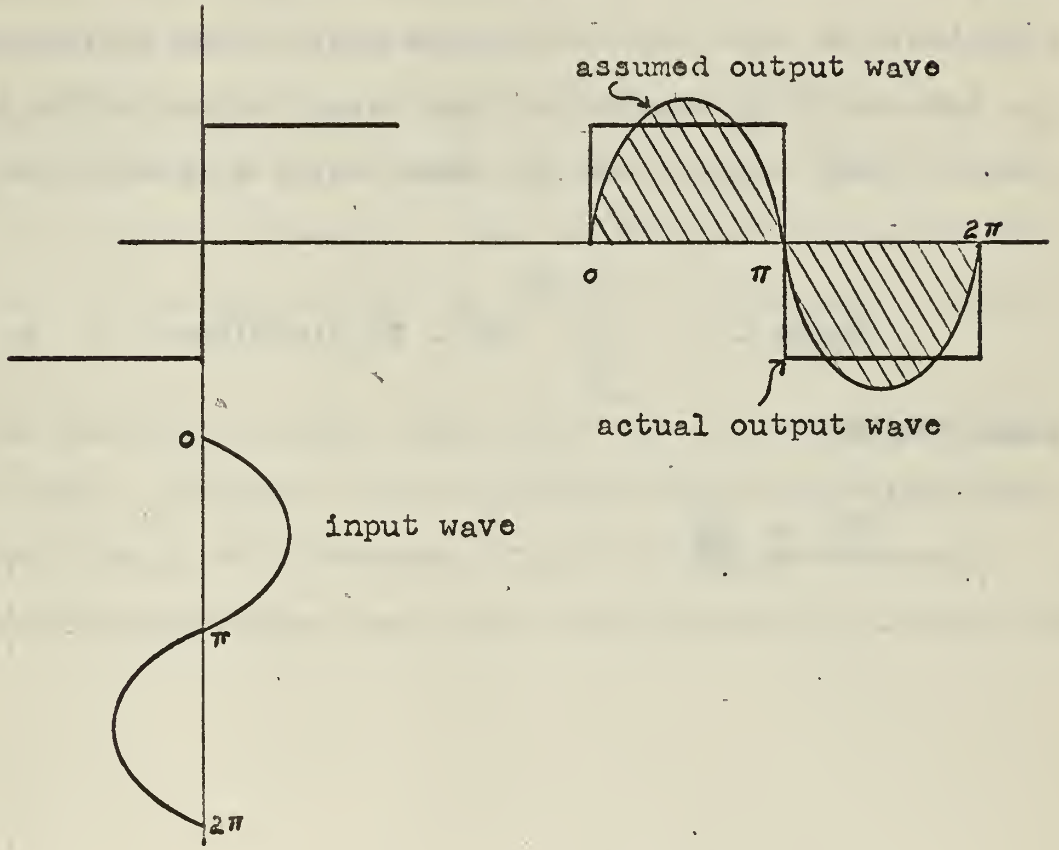


Figure 4-1. Graphical Representation of Minimum Average Error Describing Function for Ideal Relay.

5. MINIMUM ABSOLUTE VALUE ERROR DESCRIBING FUNCTION

This describing function was also developed by Gibson[6] and is very similar to the Minimum Average Error describing function. In this case the square root of the difference of the squares of the equivalent and actual waves is integrated over one half cycle. For the ideal relay this would be

$$\text{ERROR} = \int_0^{\pi} (M^2 - D^2 \sin^2\theta)^{\frac{1}{2}} d\theta = 0$$

which yields

$$GD = \frac{2M}{\sqrt{3}E}$$

6. PRINCE'S EQUIVALENT GAIN DESCRIBING FUNCTION

Prince[7] developed a describing function which is very useful for saturation types of nonlinearities. However, it is not generalized for all types of nonlinearities. The describing function is obtained by defining an equivalent gain for each nonlinearity. The magnitude of the equivalent sine wave output is defined as the peak of the actual output wave.

In Fig. 6-1 Prince's Equivalent Gain is shown to have small error. However, for a different type of nonlinearity such as a relay with deadzone (Fig. 6-1) the error would become extremely large, and this method would be unacceptable.

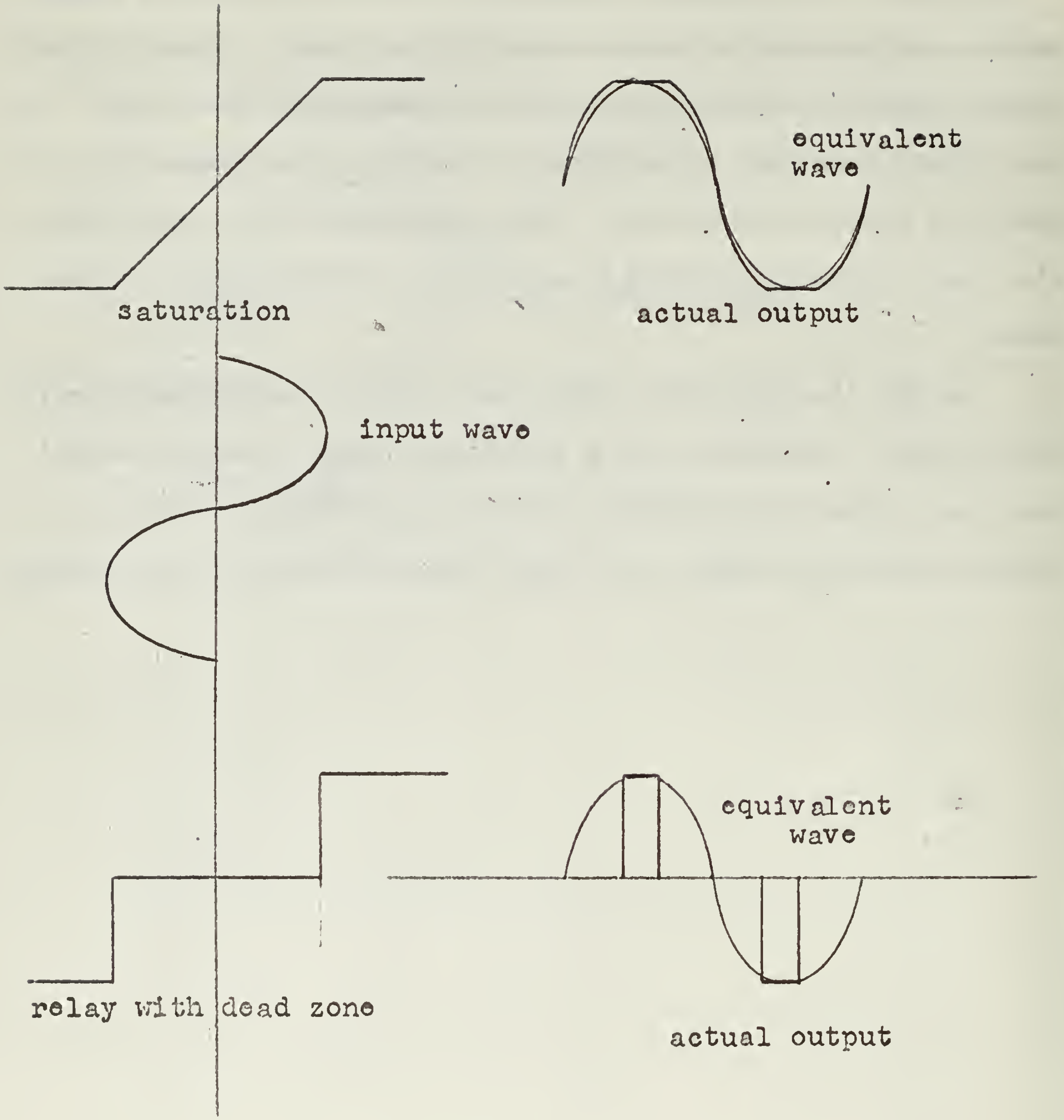


Figure 6-1. Prince's Equivalent Gain Output wave for Saturation and Relay with Dead Zone

7. OGATA'S METHOD

An additional method which has never become widely used might be mentioned here. Ogata[8] proposed a method which is most accurate with relays and limiters, but becomes quite difficult and inaccurate with other types of nonlinearities.

The method is based on the assumption of an initial wave shape at the output of the nonlinearity. This is a major disadvantage except in the cases of ideal relays and limiters since the output waveform cannot be predicted unless the magnitude of the input wave is known. The mathmatical development is quite involved and is presented in the reference material. It will not be repeated here.

8. THE NEW RMS DESCRIBING FUNCTION

This describing function was developed by Gibson and Prasanna-Kumar[9]. It is obtained by equating the rms value of the equivalent output sine wave of fundamental frequency to the rms value of the actual nonsinusoidal output of the nonlinear element in response to a sine wave input.

$$GD = \left[\frac{\frac{1}{2\pi} \int_{0}^{2\pi} \left[f(E \sin \theta) \right]^{2} \, d\theta}{\frac{1}{2\pi} \int_{0}^{2\pi} \left[(E \sin \theta) \right]^{2} \, d\theta} \right]^{\frac{1}{2}}$$

where

$E \sin \theta$ = input to nonlinearity

$f(E \sin \theta)$ = output from nonlinearity

Example

For a relay with deadzone

$$GD = \sqrt{\frac{2}{\pi} \frac{M^{2}}{E^{2}} \left[\pi - 2\sin^{-1}\left(\frac{a}{E}\right) \right]}$$

The conventional describing function for this nonlinearity is

$$GD = \frac{4M}{\pi E} \sqrt{1 - \frac{a}{E}^{2}}$$

It is seen that the New RMS describing function is more complicated, both in development and in the final result. In his development Gibson showed that the new rms method gives more accurate results than the Conventional Describing Function. However, Rankine[10] in his proposal of the Corrected-Conventional Describing Function showed that the difference in accuracy between the New RMS and the Conventional describing functions was less than one percent in magnitude in most common cases. This would hardly justify the increased labor involved.

9. CORRECTED CONVENTIONAL DESCRIBING FUNCTION

Developed by Rankine[10] this method offers an increase in accuracy as a reward for an approximate doubling of effort in calculation. Rankine showed that for several common nonlinearities the error could be cut in half from the Conventional Describing Function. The Corrected Conventional Describing Function is obtained by finding the magnitude of the square root of the sum of the squares of the first and third harmonics of the output wave, divided by the magnitude of the input.

$$GD = \frac{\left(A_1^2 + B_1^2 + A_3^2 + B_3^2\right)^{\frac{1}{2}}}{E \angle 0^\circ} \angle \tan^{-1} \frac{A_1}{B_1}$$

where

$$A_1 = \frac{2}{\pi} \int_0^{\pi} f(t) \cos wt \, dwt$$

$$B_1 = \frac{2}{\pi} \int_0^{\pi} f(t) \sin wt \, dwt$$

$$A_2 = \frac{2}{\pi} \int_0^{\pi} f(t) \cos 3wt \, dwt$$

$$B_2 = \frac{2}{\pi} \int_0^{\pi} f(t) \sin 3wt \, dwt$$

Rankine defined the phase angle as the angle whose tangent is the ratio A_1/B_1. He also restricted his derivation to nonlinearities which produce odd-harmonics thus, the third harmonic is the first above the fundamental.

10. ELLIPTIC DESCRIBING FUNCTION

The Elliptic Describing Function was developed by Jopling in an attempt to improve accuracy over the Conventional Describing Function. This new development is restricted to odd-symmetrical, single-valued, frequency-independent nonlinearities.

Nearly all describing functions for nonlinear systems specify a sinusoidal input signal. If the linear portion of the system is not a perfect low pass filter then the harmonics of the output from the nonlinear portion will be fed back into the nonlinear element, thus invalidating the assumption of sinusoidal input. In most servo-mechanisms the filtering is good, and the approximation of sinusoidal input is valid. However, for higher frequency devices, the error involved becomes unacceptable. In these cases the Elliptic describing function provides a definite advantage of increased accuracy.

The actual output of a nonlinear element is approximated by the Jacobian elliptic function which has the same amplitude and period as the actual function. Jopling obtained the amplitude of the elliptic function by minimizing the mean square error between the actual function and the approximating elliptic function.

Jopling[5] developed a set of equations for the calculation of the Elliptic Describing Function. Using these equations an example was worked out showing their use. The equations and the example are adapted from Jopling.

A study of the example makes it immediately obvious that the Elliptic Describing Function involves considerably more effort in analysis than the Conventional Describing Function, making this method advisable only when the accuracy justifies the additional labor involved. It may be noted that even with the tremendous increase in labor the error is still greater than 5%.

Example:

The steady state response for several systems was calculated using the elliptic describing function, and the results obtained were compared with the results obtained from an analog computer study. An approximation of system oscillations was also obtained using the conventional describing function method.

As an example of the application of the elliptic describing function consider the nonlinear feedback system of Fig. 1 where the nonlinear element N is an ideal relay with an output of plus or minus one, and the linear elements have a transfer function

$$G(s) = \frac{.5\,(s + 7)^2}{s\,(s + 1)^2}$$

The Nyquist plot of this transfer function is shown in Fig. 2. This Nyquist plot crosses the negative real axis at two points:

(1) The point a_1 corresponds to an unstable limit cycle.

(2) The point a_2 corresponds to a stable limit cycle with a frequency of 1.58 radians per second.

We will be concerned only with the stable limit cycle.

From the Nyquist plot, we find

$$\frac{A(3w)\cos[\phi(3\omega)-\phi(\omega)]}{A(w)} = \frac{.316\cos 2\pi}{4.70} = .067$$

A "ratio" line for the ratio .067 is sketched on Fig.10-3.

Since the gain of the linear elements to the first harmonic is 4.70, the "gain" of the nonlinear elements to the first harmonic will be approximately 1/4.70 or .213. As a crude approximation, assume the "gain" of the nonlinear device to be the ratio of the amplitude of the output to the amplitude of the input. Using this approximation, and knowing the amplitude of the output from the relay to be one, the "gain" of the nonlinear element will be approximately .213 when the amplitude of the input is .470.

To ensure that the amplitude of the normalized solution is less than one (but not too much less), let us normalize the system output according to the relationship $c' = c/10$.

Using this relationship, the normalized nonlinear relationship may be approximated by the following polynomials:

Legendre approximation $m' = 2.81\, e' - .780(e')^3$

Chebychev approximation $m' = 2.55\, e' - .667(e')^3$

Using a normalizing factor of ten, we have

$$A'(w) = \frac{A(w)}{10} = .470$$

First, let us use the elliptic describing function for the Legendre approximation of the nonlinearity.

For the values of k_i, k_o on the "ratio" line, the following values of ax_i^2 are obtained from the equation

$$ax_i^2 = \frac{k_o K_o \sinh \dfrac{(\pi K_o')}{(2K_o\ )}}{A'(w)\ bk_i K_i \sinh \dfrac{(\pi K_i')}{(2K_i\ )}} - 1.$$

k_o	k_i	ax_i^2
.99999	.54	.394
.9999	.50	.379
.999	.48	.363
.99	.43	.341
.95	.36	.318
.9	.31	.295
.8	.23	.283
.5	.15	.258

Table 10.1 Elliptic Describing Function Data

These values of ax_i^2 and k_i are plotted on Fig.10-3 to obtain a line which intersects the .067 "ratio" line.

This intersection gives us the following parameters of the elliptic function approximation of system oscillations:

$k_i = .38$

$ax_i^2 = .320$

Thus, we have

$$x_i = \sqrt{\frac{ax_i^2}{a}} = \sqrt{\frac{.320}{.78}} = .640$$

This is the amplitude of oscillations for the normalized system. The amplitude for the unnormalized system is 6.40.

Therefore the elliptic function approximation of system oscillations is

$$c = 6.40\ \mathrm{sn}(1.64t,\quad .38)$$

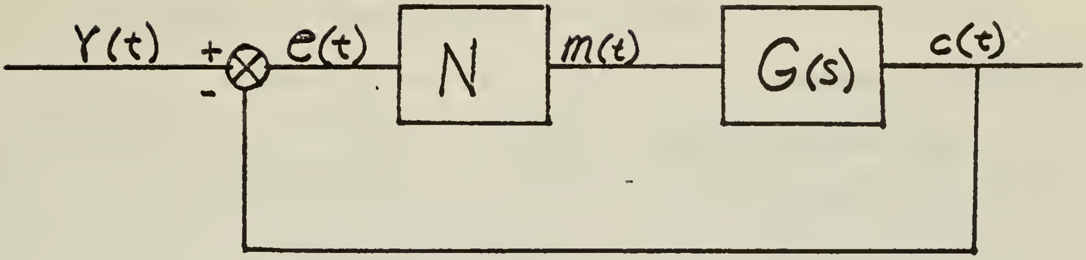


Figure 10-1. Closed Loop Block Diagram for Example of Elliptic Describing Function Application

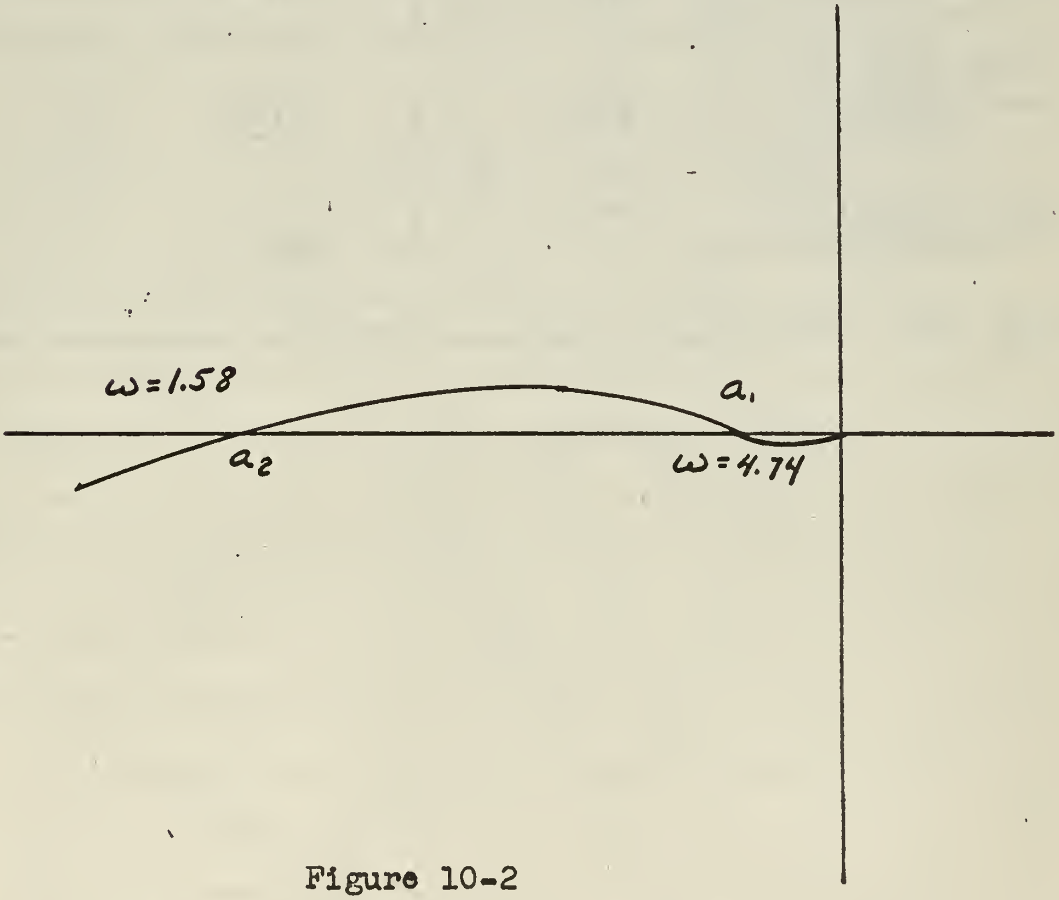


Figure 10-2

Nyquist Plot of Example of Application of Elliptic Describing Function.

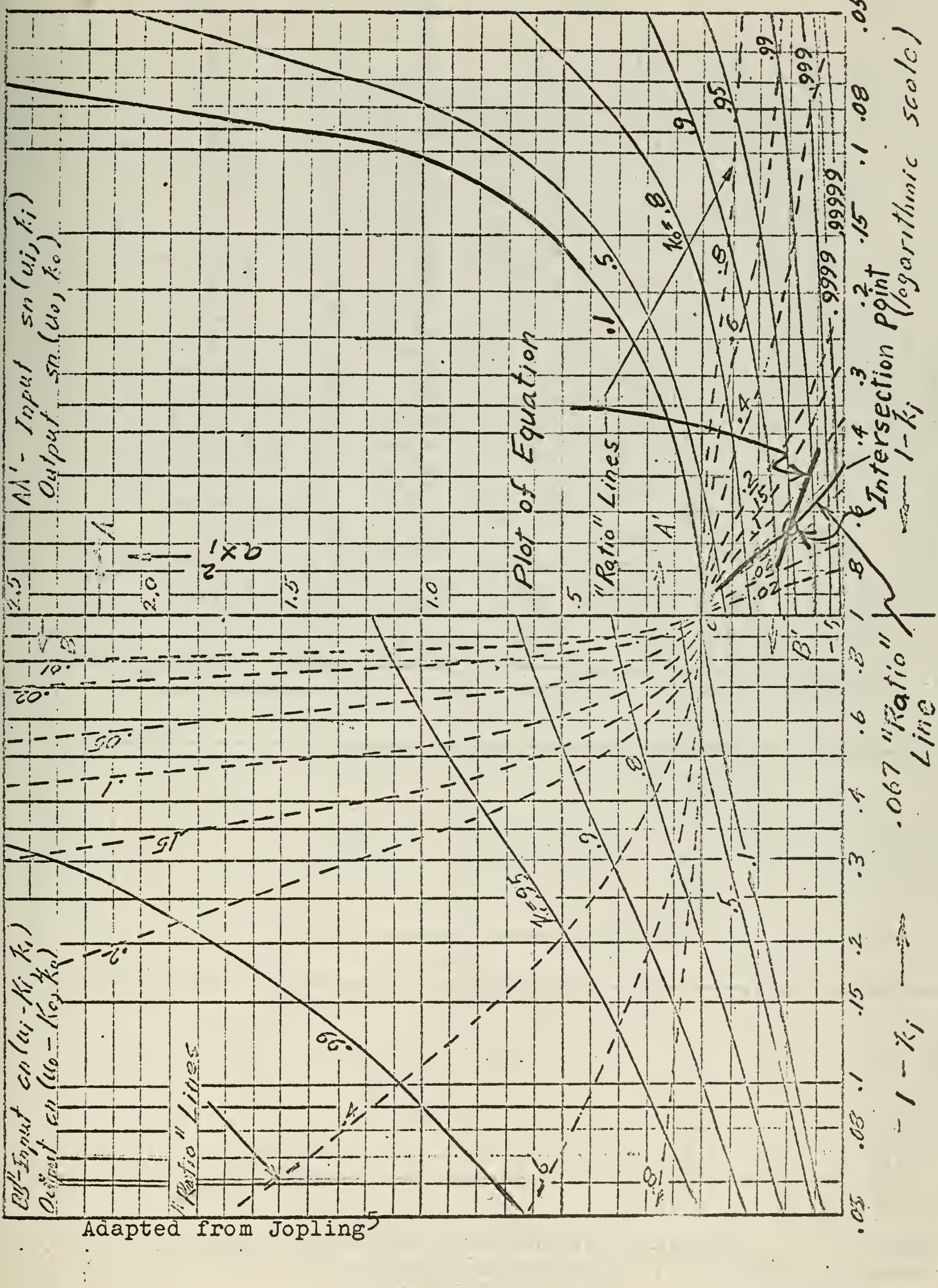
Similarly, the Chebychev approximation yields the following result:

$$c = 6.48 \, \mathrm{sn}(1.72t, \quad .54)$$

Results

	Analog Computer Simulation	Conventional Describing Function	Elliptic Describing Function
Amplitude of Oscillations	6.85	5.98	6.40
Frequency of Oscillations	1.55	1.58	1.58
Percent Error In Amplitude	——	12.7	5.83

Table 10-2 Comparative Results of Elliptic Describing Function



Adapted from Jopling[5]

Composite Plot of the Elliptic Describing Function Relationship and the $A(3\omega)\cos[\phi'(3\omega)-\phi(\omega)]$ to $A'(\omega)$ Relationship (Expanded Scale)

Figure 10-3

Input	Output	Equations for ax_i^2
$x_i sn(u_i,k_i)$	$x_o cn(u_o-K_o,k_o)$	$ax_i^2 = \dfrac{\left\{ \frac{-2}{k_o}\int_0^{K_o}\left[\frac{u_o-E(u_o)}{(k_o')^2}\right] sn(u_o-K_o,k_o)dn(u_o-K_o,k_o)sn(u_i,k_i)du_o \; \frac{-2k_o}{(k_o')^2}\int_0^{K_o} cn(u_o-K_o,k_o)sn^2(u_o-K_o,k_o)sn(u_i,k_i)du_o + G \right\}}{\left\{ -G + \frac{2}{k_o}\int_0^{K_o}\left[\frac{u_o-E(u_o)}{(k_o')^2}\right] sn(u_o-K_o,k_o)dn(u_o-K_o,k_o)sn^3(u_i,k_i)du_o - \frac{2k_o}{(k_o')^2}\int_0^{K_o} cn(u_o-K_o,k_o)sn^2(u_o-K_o,k_o)sn^3(u_i,k_i)du_o \right\}}$
$x_i cn(u_i-K_i,k_i)$	$x_o cn(u_o-K_o,k_o)$	$ax_i^2 = \dfrac{\left\{ \frac{-2}{k_o}\int_0^{K_o}\left[\frac{u_o-E(u_o)}{(k_o')^2}\right] sn(u_o-K_o,k_o)dn(u_o-K_o,k_o)cn(u_i-K_i,k_i)du_o \; \frac{-2k_o}{(k_o')^2}\int_0^{K_o} cn(u_o-K_o,k_o)sn^2(u_o-K_o,k_o)cn(u_i-K_i,k_i)du_o + G \right\}}{\left\{ -G + \frac{2}{k_o}\int_0^{K_o}\left[\frac{u_o-E(u_o)}{(k_o')^2}\right] sn(u_o-K_o,k_o)dn(u_o-K_o,k_o)cn^3(u_i-K_i,k_i)du_o \; \frac{-2k_o}{(k_o')^2}\int_0^{K_o} cn(u_o-K_o,k_o)sn^2(u_o-K_o,k_o)cn^3(u_i-K_i,k_i)du_o \right\}}$

Table 10-3. Equations for the Calculation of Elliptic Describing Function. (Adapted from Jopling[5])

Input	Output	Equations for ax_i^2
$x_i sn(u_i,k_i)$	$x_o sn(u_o,k_o)$	$ax_i^2 = \dfrac{\left\{ \frac{2}{k_o}\int_0^{K_o}\left[u_o - \frac{E(u_o)}{(k_o')^2}\right] cn(u_o,k_o)dn(u_o,k_o)sn(u_i k_i)du_o + \frac{2k_o}{(k_o')^2}\int_0^{K_o} sn(u_o,k_o)cn^2(u_o,k_o)sn(u_i,k_i)du_o - G \right\}}{\left\{ G - \frac{2}{k_o}\int_0^{K_o}\left[u_o - \frac{E(u_o)}{(k_o')^2}\right] cn(u_o,k_o)dn(u_o,k_o)sn^3(u_i,k_i)du_o + \frac{2k_o}{(k_o')^2}\int_0^{K_o} sn(u_o,k_o)cn^2(u_o,k_o)sn^3(u_i,k_i)du_o \right\}}$
$x_i cn(u_i-K_i,k_i)$	$x_o sn(u_o,k_o)$	$ax_i^2 = \dfrac{\left\{ \frac{2}{k_o}\int_0^{K_o}\left[u_o - \frac{E(u_o)}{(k_o')^2}\right] cn(u_o,k_o)dn(u_o,k_o)cn(u_i-K_j,ki)du_o + \frac{2k_o}{(k_o')^2}\int_0^{K_o} sn(u_o,k_o)cn^2(u_o,k_o)cn(u_i-K_i,k_i)du_o - G \right\}}{\left\{ G - \frac{2}{k_o}\int_0^{K_o}\left[u_o - \frac{E(u_o)}{(k_o')^2}\right] cn(u_o,k_o)dn(u_o,k_o)cn^3(u_i-K_i,k_i)du_o + \frac{2k_o}{(k_o')^2}\int_0^{K_o} sn(u_o,k_o)cn^2(u_o,k_o)cn^3(u_i-K_i,k_i)du_o \right\}}$

Table 10-3 (cont). Equations for the Calculation of Elliptic Describing Function

11. EXPONENTIAL DESCRIBING FUNCTION

Sinusoidal analysis provides a valuable tool for analysis of periodic, steady state systems. However for transient analysis sinusoidal techniques fail, and other methods must be used. Since most transients are exponential in nature it is obvious that an exponential approximation be chosen to represent the describing function of a nonlinearity. Beckart[39] developed one such approximation technique, but the development and use of this technique is quite lengthy and involved mathmatically. Since transient behavior is beyond the scope of this paper, the development of the Exponential Describing Function will not be summarized.

12. DUAL INPUT DESCRIBING FUNCTION (DIDF)

All standard methods of describing functions fail if the input is non-sinusoidal or if there is more than one input signal. West, Douce, and Livesley[30] developed a method whereby two input signals could be handled provided one was a multiple frequency of the other.

Specifically

$$E_{in} = a_1 \cos(wt + \phi) + b_1 \cos nwt$$

The output would then have frequency components at both frequencies.

$$E_{out} = a_2 \cos(wt + \phi + \gamma) + b_2 \cos(nwt + \beta) + \cdots$$

where γ and β are the phase shifts of the individual output components. Two describing functions may then be defined, one for each frequency:

$$GD_1 = \frac{a_2}{a_1} \angle \gamma \qquad GD_2 = \frac{b_2}{b_1} \angle \beta$$

Practical arrangements where two inputs occur are those of forced oscillations and the closed loop considered previously with an interfering signal. Figs. 12-1 and 12-2.

There are several variables which complicate the problem:

a. The amplitude of the two input waves a_1 and b_1

b. The differences in phase of the input waves (ϕ).

c. The multiple difference in frequency of the two input waves (n).

The analysis of the DIDF becomes a complex problem involving a large amount of computation and data. The situation is not hopeless, however. West, et al. showed a breakthrough in several areas, namely:

a. Stability of forced oscillations
b. Possible existance of jump phenomena
c. Amplitude stability of conditionally stable systems
d. Subharmonic oscillations

The DIDF appearson the complex plane as a family of loops with the variable distinguishing one loop from another being the amplitude (a_2) of the subharmonic output wave (the amplitude of the fundamental (b_2) being normalized to 1). The location on a particular loop is determined by the phase difference between input and output. The amplitude and phase of the oscillatory mode may be determined by superposition of a Nyquist diagram. The second describing function may be analyzed by reversing the above process.

Jelonek, Pomella, and Karunaratne[36] showed that the incremental describing function (i.e. a transfer function for a small increment to the oscillation) is in fact a circle for any type of periodic interference and for any frequency independent nonlinearity. This makes the construction of the loops considerably simpler.

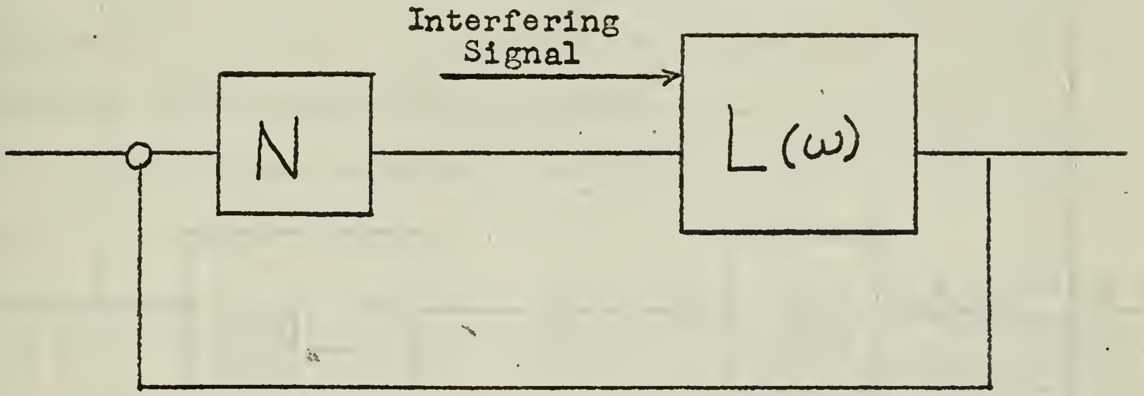


Figure 12-1a Block Diagram of Closed Loop System With Interfering Signal.

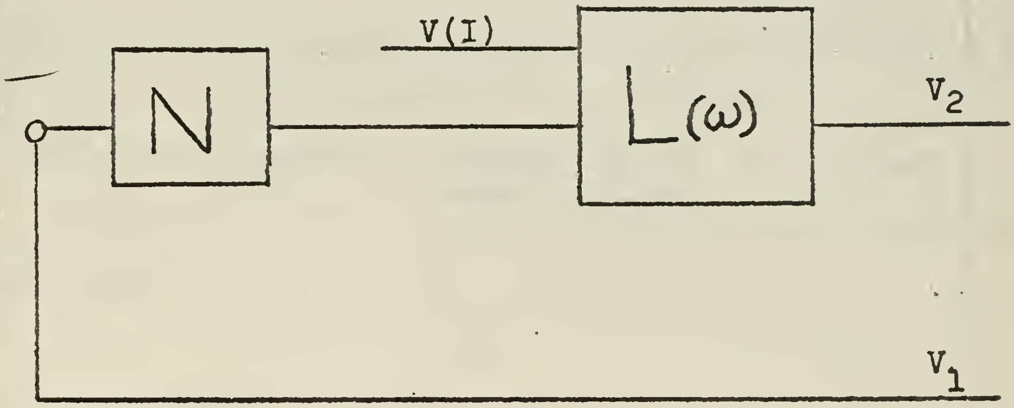


Figure 12-1b Block Diagram of Open Loop System With Interfering Signal.

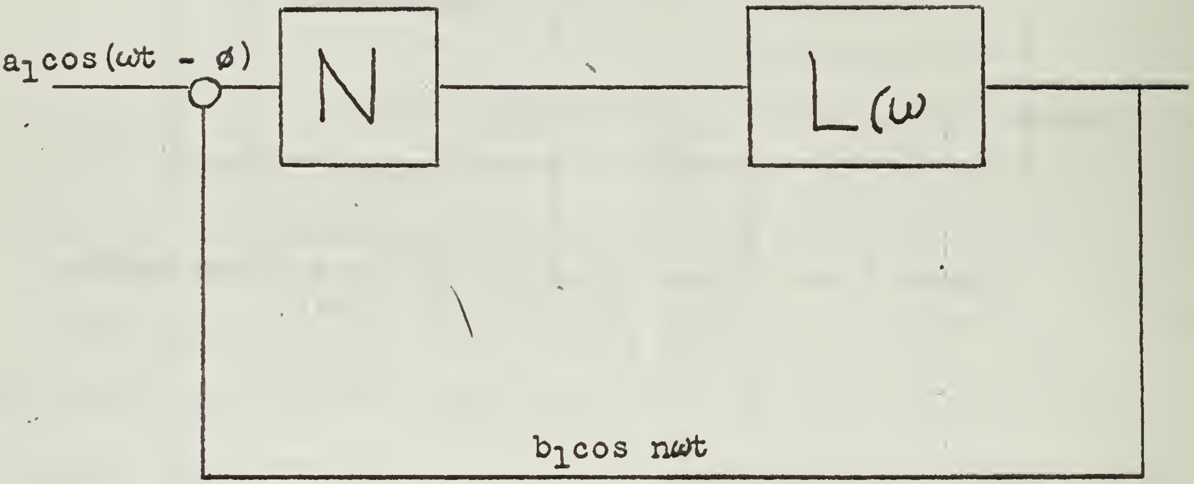


Figure 12-2 Block Diagram of System With Forced Oscillations.

Jelonek et al. also made several important conclusions regarding stability analysis using DIDF. In general if the formula for the DIDF is known, information is available in analytical form for determining two necessary and sufficient conditions for stable oscillations.

a. The loop obtained for a point P on the DIDF must not encircle P.

b. Moving along the plot of the inverse Nyquist diagram (of the linear part of the system) in the direction of increasing w, the center of the loop must lie to the left. This is an approximation which improves in accuracy as the size of the loop decreases with respect to the radius of curvature of the inverse Nyquist plot in that particular area.

If a graph of the DIDF is available, condition (a) may be determined by inspection, and condition (b) may be determined by a simple geometric construction.

BIBLIOGRAPHY

1. G.J. Thaler and M.P. Pastel, Analysis and Design of Nonlinear Feedback Control Systems, McGraw-Hill Book Company, Inc. New York, 1962.

2. R.M. Nutting, "Parameter Plane Techniques for Feedback Control Systems", M.S. thesis, U.S. Naval Postgraduate School, Monterey, California, May 1965.

3. J.C. West, Analytical Techniques for Nonlinear Control Systems, English University Press, 1960.

4. H.C. Brearley Jr., "Prediction of Transient Response of Nonlinear Servomechanisms by Sinusoidal Analysis", Ph.D. thesis, University of Illinois, 1954.

5. A.D. Jopling, "A Study of Describing Function Techniques", M.S. thesis, University of Manitoba, Canada, Feb. 1963.

6. J.E. Gibson, Nonlinear Automatic Control, McGraw-Hill Book Company, Inc. New York, 1963.

7. L.T. Prince Jr., "A Generalized Method for Determining The Closed Loop Frequency Response of Nonlinear Systems," Trans AIEE Vol 73, Part II, pp 217-224, 1954.

8. K. Ogata, "An Analytic Method for Finding the Closed-Loop Frequency Response of Nonlinear Feedback Control Systems", Trans AIEE, Vol. 76, Part II pp 277-285, 1957.

9. J.E. Gibson and K.S. Prasanna-Kumar, "A New RMS Describing Function for Single-valued Nonlinearities", Proc. IRE Vol 49, p 1321, 1961

10. R.R. Rankine, "An Evaluation of Selected Describing Functions of Control System Nonlinearities", M.S. thesis USAF Institute of Technology Air University, 1964.

11. R. Kochenburger, "Frequency Response Method of Analysis of a Relay Servo-mechanism", Trans. AIEE, Vol 69, pp 270 - 283, 1950.

12. L.C. Goldfarb, "On Some Nonlinear Phenomena in Regulatory Systems", Automatika i Telemekhanika, Vol 8, No. 5 pp 349-383, September-October, 1947. Reprinted in Frequency Response, The MacMillan Company, New York, 1956.

13. A. Tustin, "The Effects of Backlash and of Speed-development Friction on the Stability of Closed-cycle Control Systems," J. Inst. Elec. Engrs. (London), Vol 94, Part IIA No. 1, 1947.

14. W. Oppelt, "Locus Curve Method For Regulators with Friction," *J. Inst. Elec. Engrs. (London)*, Vol. 94, Part IIA, Nos. 1 and 2, May, 1947.

15. J.C. Gille, M.J. Pelegrin and P. Decaulne, *Feedback Control Systems*, McGraw-Hill Book Company, Inc., New York, 1959.

16. R. Sridhar, "A General Method for Deriving the Describing Functions for a Certain Class of Nonlinearities," *IRE Trans. on Automatic Control*, Vol. AC-5, pp 135-141, 1960.

17. A.D. Gronner, "Describing Function of Backlash Followed by Dead Zone," *Trans. AIEE*, Vol. 77, part 2 pp 403-409, 1958.

18. K.N. Satyendra, System Inertia, "Backlash and Coulomb Friction-I," *Trans. AIEE*, Vol. 75, part 2, pp 243-249, 1956.

19. M.Y. Silberberg, "The Describing Function of an Element with Friction," *Trans. AIEE*, Vol. 75, part 2, pp 423-425, 1956.

20. J. Zaborszky and H.J. Harrington, "Describing Function for Hydraulic Valves," *Trans. AIEE*, Vol. 76, part I, pp 183-198, 1957.

21. E.C. Johnson, "Sinusoidal Analysis of Feedback Control Systems Containing Nonlinear Elements," *Trans. AIEE*, Vol. 71, part II, pp 169-181, 1952.

22. J.G. Truxal, "Automatic Feedback Control System Synthesis," pp 598-612, McGraw-Hill Book Company, Inc. New York, 1955.

23. R.W. Bass, "Mathematical Legitimacy of Equivalent Linearization by Describing Functions," *Proc. First Intern. Congress on Automatic Control*, IFAC, Moscow, 1960.

24. K. Klotter, "An Extension of the Conventional Concept of the Describing Function," *Proc. Symposium on Nonlinear Circuit Analysis*, Brooklyn Polytechnic Institute, 1956.

25. R.C. Booton Jr., "The Analysis of Nonlinear Control Systems with Randon Inputs," *Proc. Symposium on Nonlinear Circuit Analysis*, Vol. II, pp 369-391, Brooklyn Polytechnic Institute, 1953.

26. E. Levinson, "Some Saturation Phenomena in Servomechanisms with Emphasis on the Tachometer Stabilized System," *Trans. AIEE*, Vol. 73, part II, pp 1-9, 1953.

27. W.A. Stein and G.J. Thaler, "Obtaining the Frequency Response Characteristic of a Nonlinear Servomechanism for an Amplitude - and Frequency - Sensitive Describing Function," Trans. AIEE, Vol. 77, part II, pp 91-96, 1958.

28. A.S. McAllister, "A Graphical Method for Finding the Frequency Response of Nonlinear Closed-loop Systems," Trans. AIEE, Vol. 80, part II, pp 268-277, 1961.

29. J.C. Hill, "Closed Loop Response of Nonlinear Systems by a Functional Transformation Approach," IRE Trans. On Automatic Control, Vol. AC-7, no. 4, pp 39-45, 1962.

30. J.C. West, J.L. Douce, and R.K. Livesley, "The Dual-input Describing Function and Its Use in the Analysis of Non-linear Feedback Systems," Proc. IEE, Vol. 103, part B, pp 463-474, 1956.

31. C. Hayashi, Forced Oscillations in Nonlinear Systems, Nippon Printing and Publishing Company, Ltd., Osaka, Japan, 1953.

32. R.C. Boyer, "Sinusoidal Signal Stabilization," M.S. thesis Purdue University, Lafayette, Ind., Jan., 1960.

33. R. Sridhar, "Signal Stabilization of a Control System with Random Inputs," Ph. D. thesis, Purdue University, Lafayette, Ind., Jan., 1960.

34. J.E. Gibson and R. Sridhar, "A New DIDF and an Application to the Stability of Forced Nonlinear Systems, Sec. 9," Proc. Joint Automatic Control Council (JACC), New York, June, 1962.

35. C.N. Shen, "Synthesis of Compensating Servomechanism with Backlash by Incorporating Nonlinear Saturable Velocity Feedback," Proc. First Congress, International Federation for Automatic Control, Moscow, 1960.

36. A.J. Jelonek, P.L.V. Pomella, N.S. Karunaratne, "Oscillations in Feedback Systems Subjected to Periodic Interference and Stability of a Self-optimising Control System," Proc. IEE, Vol. III, No. 11, pp 1881-1893, Nov. 1964.

37. J.C. West and J.L. Douce, "The Mechanism of Subharmonic Generation in a Feedback Control System," Proc. IEE, 1955, 102B, pp 569.

38. J.L. Douce and R.E. King, "Instability in a Nonlinear Conditionally Stable System Subjected to a Sinusoidal Input," Trans AIEE, 1958, 77, pp 665.

39. T.A. Beckart, "The Exponential D.F. in the Analyses of Nonlinear Systems," Proc. Third Annual Allerton Conference on Circuit and System Theory (IEEE). Monticello, Ill., 1965.

40. P.L.V. Pomella, "Study of the Stability of Servomechanisms with Backlash," Ph.D. thesis, Glasgow University, 1963.

41. N.S. Karunaratne, "Stability of a Self-Optimising Control System," M.S. thesis, Glasgow University, 1963.

42. R.L. Cosgriff, "Nonlinear Control Systems," McGraw Hill, 1958.

43. A.C. Soudack, "The Use of Jacobian Elliptic Functions in the Analysis of a Nonlinear Circuit," IEEE Trans. on Circuit Theory, March 1964, pp 118-122.

44. J.J. D'Azzo and C.H. Houpis, Feedback Control System Analysis and Synthesis, McGraw-Hill Book Company, Inc. New York, 1960.

45. N.B. Nichols, "Backlash in A Velocity Lag Servomechanism," Trans. AIEE, Part II, 1953.

46. C.A. Pellegrini, "An Investigation of Nonlinear System Performance on The Parameter Plane," M.S. thesis, U.S. Naval Postgraduate School, Monterey, California, May 1966

47. D.D. Siljak,"Analysis and Synthesis of Feedback Systems in the Parameter Plane, Part I, Linear Continuous Systems, Part III, Nonlinear Systems," IEEE Transactions on Applications and Industry. Nov. 1964.

48. H.M. Yockey and G.J. Thaler, "Analysis of A Control System with Two Nonlinearities," Unpublished Paper, U.S. Naval Postgraduate School, 1965.

49. E.E. Schiring, "Effect of Saturation on the Dynamic Response of a Class of Bang-Bang Control Systems," Ph.D. thesis, University of Pittsburg, 1963.

50. D.P. Donohue, "EE416 Project" Unpublished Paper, U.S. Naval Postgraduate School, 1964.

51. Truxal, J.G. (ed), Control Engineers Handbook, pp 2-67 to 2-86, McGraw Hill Book Company, New York, 1958.

52. Grief, H.D. Describing Function Method of Servomechanism Analysis Applied to Most Commonly Encountered Nonlinearities, Trans. AIEE, pt II, 1953.

53. R.E. Finnigan, "Transient Analysis of Nonlinear Servomechanisms Using Describing Functions with Root Locus Techniques," Ph.D. thesis, University of Illinois, 1957.

APPENDIX I

Use of Real and Imaginary Components of the Describing Function

Consider the system in Fig. I-1. The characteristic equation is:

$$F(s) = as^2 + bs + c + KN = 0 \qquad 13\text{-}1$$

Assume N introduces a phase shift. $N = \alpha + j\beta$ Nutting[2] showed that by developing and plotting the parameter plane equations the system stability can be studied. If a nonlinearity is introduced into the system the parameter plane criteria must be modified.

The parameter plane equations are derived for zeta = 0 which is the vertical axis on the A-plane, and indicates the limit of stability. These equations are then plotted as a function of frequency. In addition the real and imaginary components of the describing function of the nonlinearity are plotted. An intersection of the zeta = 0 curve and the describing function curve indicates equal values of and and thus a limit of stability at that point. The values of the limit cycle can then be determined.

Factoring the general characteristic equation for a second order system

$$s^2 + 2\zeta w_n s + w_n^2 = 0 \qquad 13\text{-}2$$

$$s = -\zeta w \pm jw\sqrt{1 - \zeta^2} \qquad 13\text{-}3$$

Substituting this into equation 13-1 gives for the second quadrant (S $= -\zeta w + jw\sqrt{1-\zeta^2}$)

$$F(s) = aw^2(2\zeta^2 -1) -bw\zeta + c + K\alpha + j(-2aw^2\zeta\sqrt{1-\zeta^2}\; bw\sqrt{1-\zeta^2} + K\beta) = 0 \qquad 13\text{-}4$$

Setting the real and imaginary components to zero independently gives

$$\alpha = \frac{aw^2(1 -2\zeta^2) + b\zeta w - c}{K} \qquad 13\text{-}5a$$

$$\beta = \frac{-2aw^2\zeta\sqrt{1-\zeta^2} + bw\sqrt{1-\zeta^2}}{K} \qquad 13\text{-}5b$$

Equations for the third quadrant may be similarly derived by substituting S $= -\zeta - jw\sqrt{1-\zeta^2}$ or obtained directly by substituting $-\zeta$ and $-w$ into eqs 13-5a,b giving:

$$= \frac{aw^2(1 -2\zeta^2) + b\zeta w - c}{K} \qquad 13\text{-}6a$$

$$= \frac{2\alpha w^2\zeta\sqrt{1-\zeta^2} - bw\sqrt{1-\zeta^2}}{K} \qquad 13\text{-}6b$$

To determine stability consider the zeta = 0 curve on the parameter plane. Considering a particular system where (See Fig. I-1)

$$G = \frac{4.9}{s(s+1)}$$

N = Friction Controlled Backlash

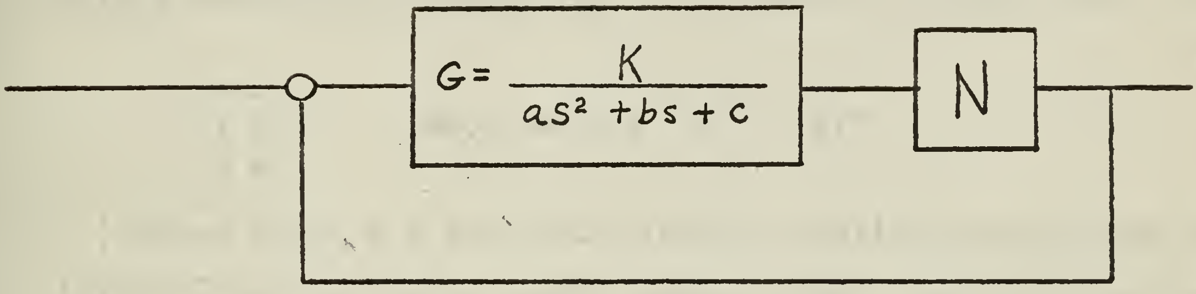


Figure I-1. Block diagram of typical Second order system containing nonlinearity

The characteristic equation of the linear system is

$$F(s) = s^2 + s + 4.9$$

and $$\omega_n = 2.21, \qquad \zeta = .404$$

The characteristic equation of the complete nonlinear system is

$$F(s) = s^2 + s + 4.9N \qquad \begin{array}{l} a = 1 \\ b = 1 \\ c = 0 \end{array}$$

To determine stability consider the zeta = 0 curve on the parameter plane. The parameter plane equations are obtained by substituting $\zeta = 0$ into equations 13-5a,b and 13-6a,b. For the second quadrant the equations reduce to

$$\alpha = \frac{w^2}{K} \tag{13-7a}$$

$$\beta = -\frac{w}{K} \tag{13-7b}$$

Third quadrant

$$\alpha = \frac{w^2}{K} \tag{13-8a}$$

$$\beta = \frac{w}{K} \tag{13-8b}$$

An examination of the plot of the real and imaginary components of the backlash describing function shows that eqs 13-8a,b cannot possibly produce an intersection. Therefore, only equations 13-7a,b are plotted in Fig. I-2.

The intersections shown indicates a limit cycle at w = 1.56 with a backlash to amplitude ration of 0.5. The limit cycle predicted at $R = .189$, $w = .34$ does not exist as shown by Nichols.[45] An analog computer simulation of this problem gave a limit cycle at $R = .19$, $w = .3$.

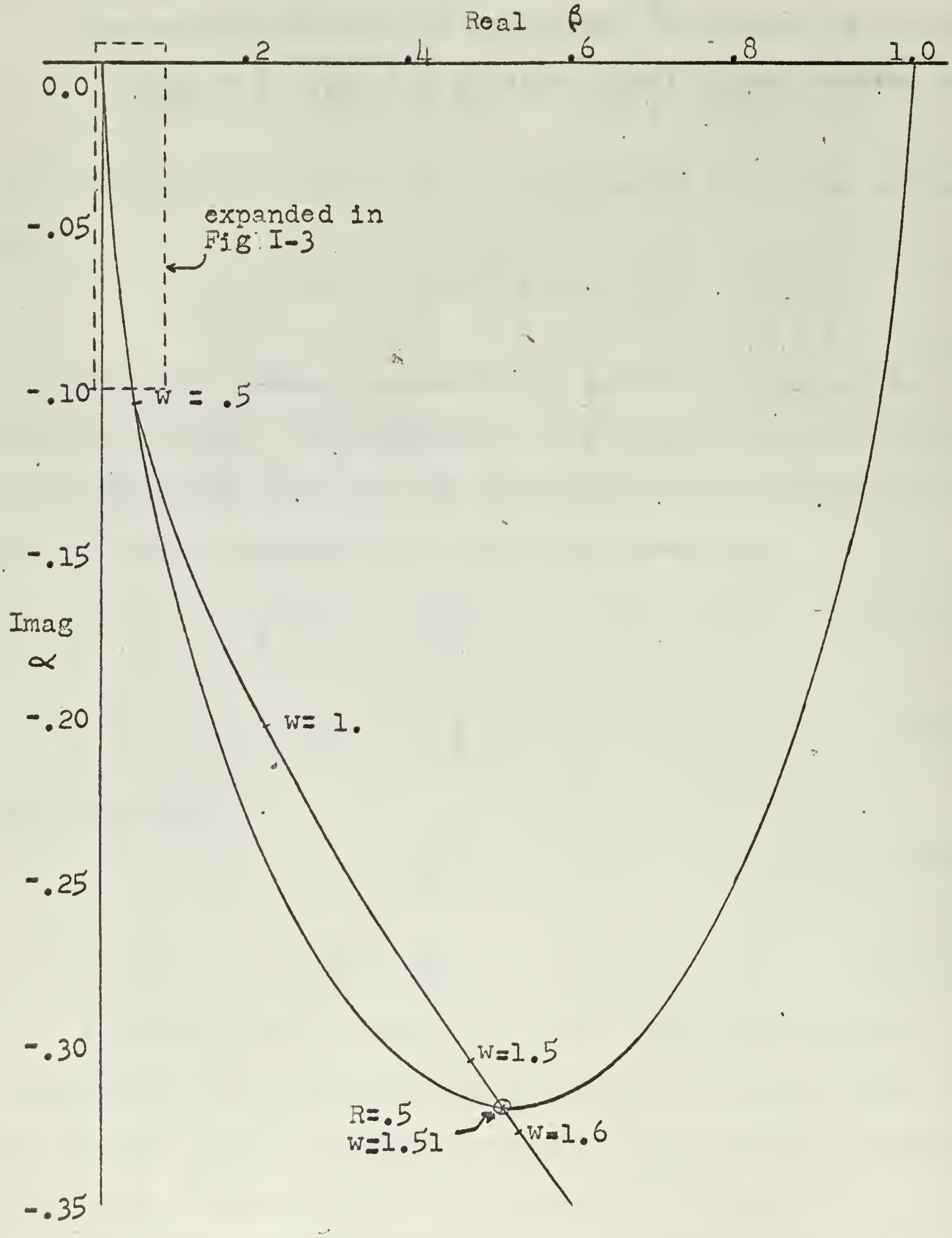


Figure I-2. Parameter Plane Plot Showing Intersection Giving Limit of Stability.

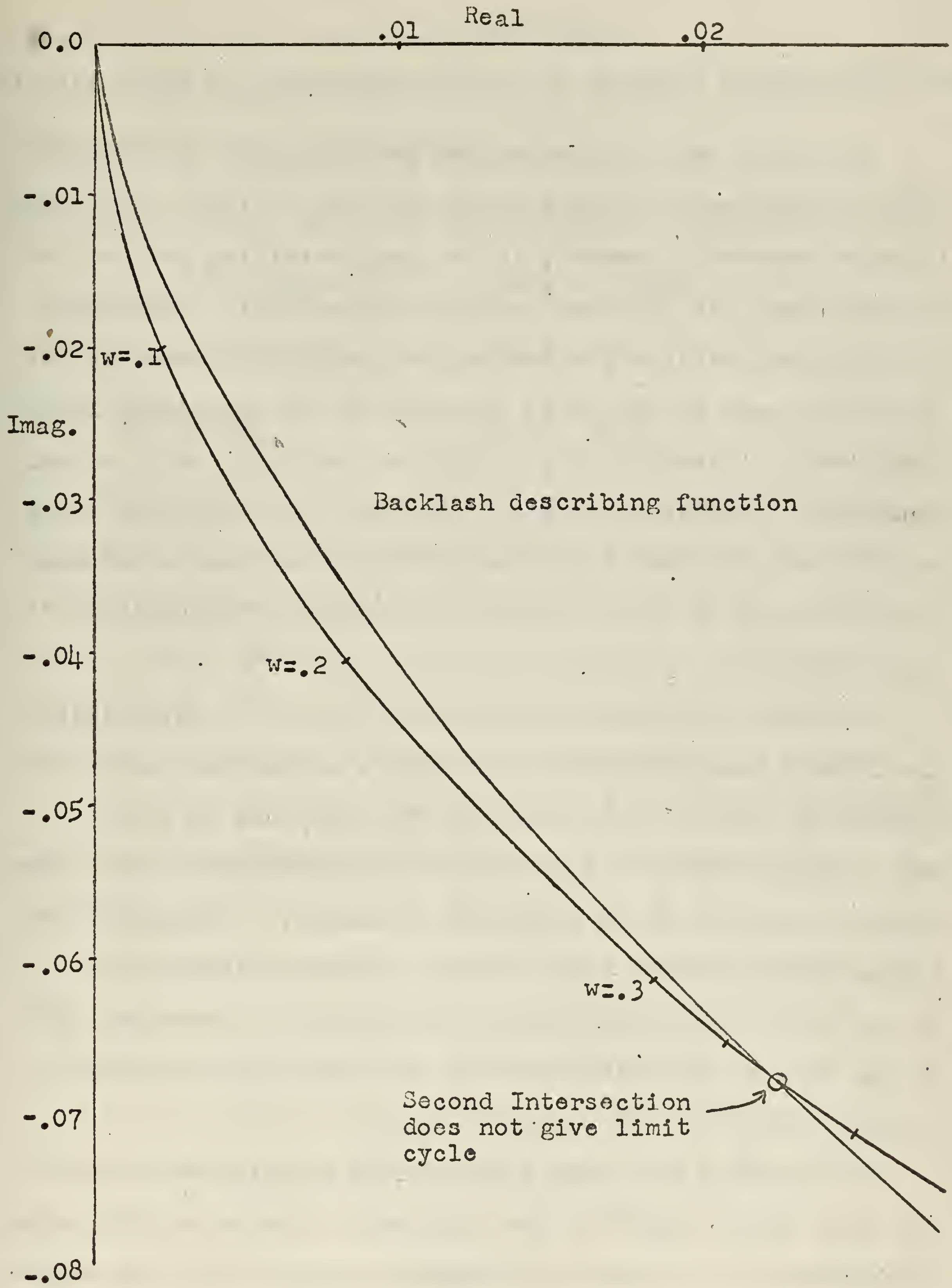


Figure I-3. Expanded Portion of Parameter Plane Curve (Figure I=2).

APPENDIX II

Use of Describing Function in System Containing Two Nonlinearities

If two or more nonlinearities are connected in a series path they may be combined for analysis and a single describing function derived. However, if the nonlinearities are not in the same path, or if other factors prevent their combination the concepts previously shown must be modified. Several conditions must be satisfied in order to use describing function theory. First of all, as before, the input must be near sinusoidal, implying low pass filtering in any feedback paths. In addition, low pass filtering must also be present between nonlinearities in order that the assumption of sinusoidal input be valid.

Consider the system shown in Fig. II-1. In determining the dynamic describing function curve a sinusoidal input is assumed at point A. The input to N_1 will then be A G_1 . Note that the input to N_1 is frequency dependent if the linear transfer function G_1 is frequency dependent. The output from N_1 can be determined, and if it is properly filtered through G_2 the input to N_2 will again be sinusoidal. The output of N_2 can then be determined and the real, and imaginary components plotted on the parameter plane.

In plotting the dynamic describing function curve only the phase shift caused by the nonlinear elements is considered in determining the real and imaginary components of the output wave. The phase shift caused by the linear elements is considered in the parameter plane curves.

Considering a particular system as shown in Fig. II-2 the characteristic equation is:

$$F(s) = s^3 + 3s^2 + 2s + 40K(N_1N_A + jN_1N_B) = 0 \qquad \text{II-1}$$

$$= \frac{s^3 + 3s^2 + 2s}{40K} + N_1N_A + jN_1N_B = 0$$

The parameters chosen to be plotted are:

$$\alpha = N_1N_A \qquad \beta = N_1N_B$$

The parameter plane equations can then be determined from Nutting[2] or the parameter plane curves may be generated by program PARAMA also developed by Nutting[2]. These curves can be generated and plotted directly for various values of ζ and w. For the stability analysis only the family of curves for $\zeta = 0$ need be considered. A solution to equation II-1 will exist, indicating a limit of stability, when the dynamic describing function curve intersects a parameter plane curve at equal values of w.

Two runs were made using different values of gain. In the first case, Fig. II-3, for K = .15 a limit cycle is predicted with a signal input amplitude of .23 and w = .52. In the second case, Fig. 4, the gain K was raised to .25. The limit cycle is predicted at A = .45, w = .68. Since the magnitude of the limit cycle did not include the effects of the frequency sensitive elements, it is necessary to multiply that magnitude by $N_1 \left|G_1(jw)\right| \left|G_2(jw)\right|$ in order

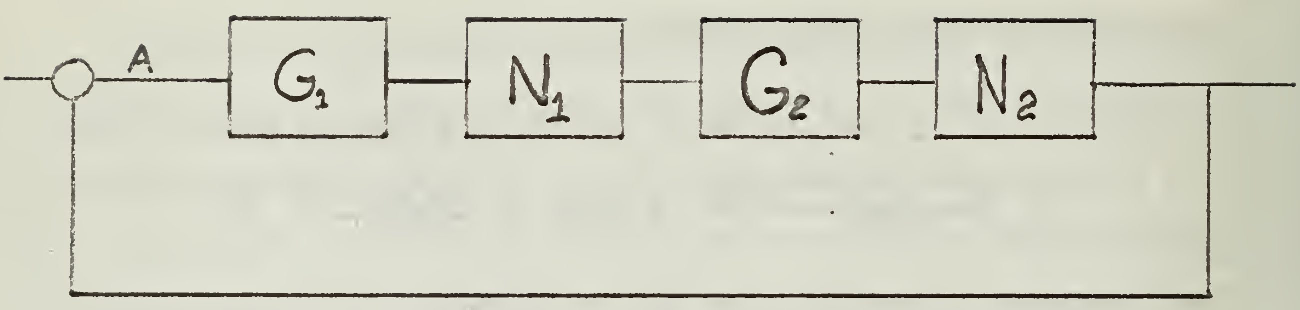


Figure II-1. Block Diagram of Typical System Containing Two Nonlinearities

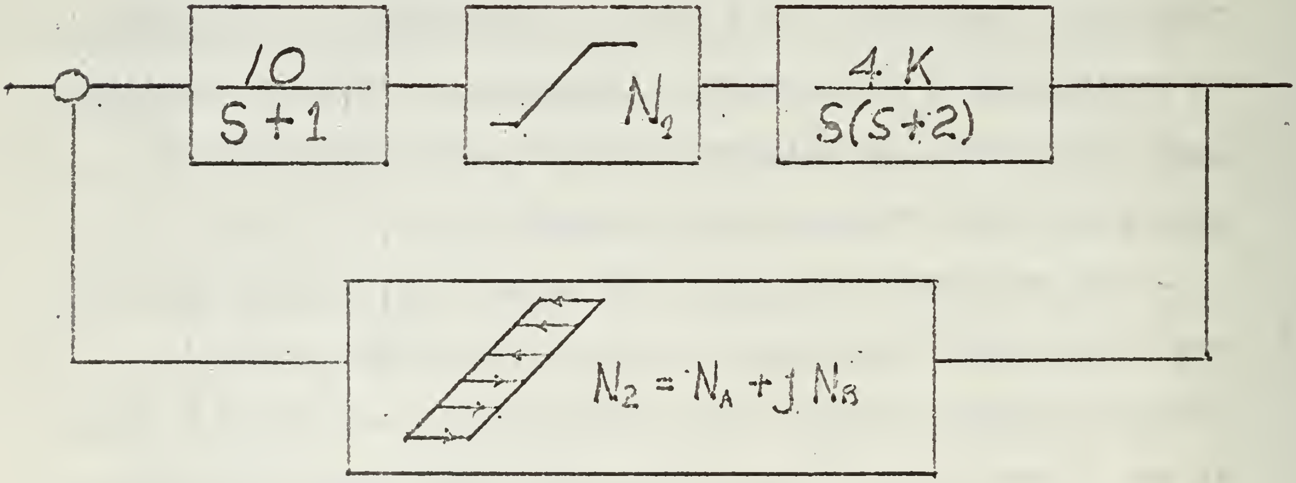
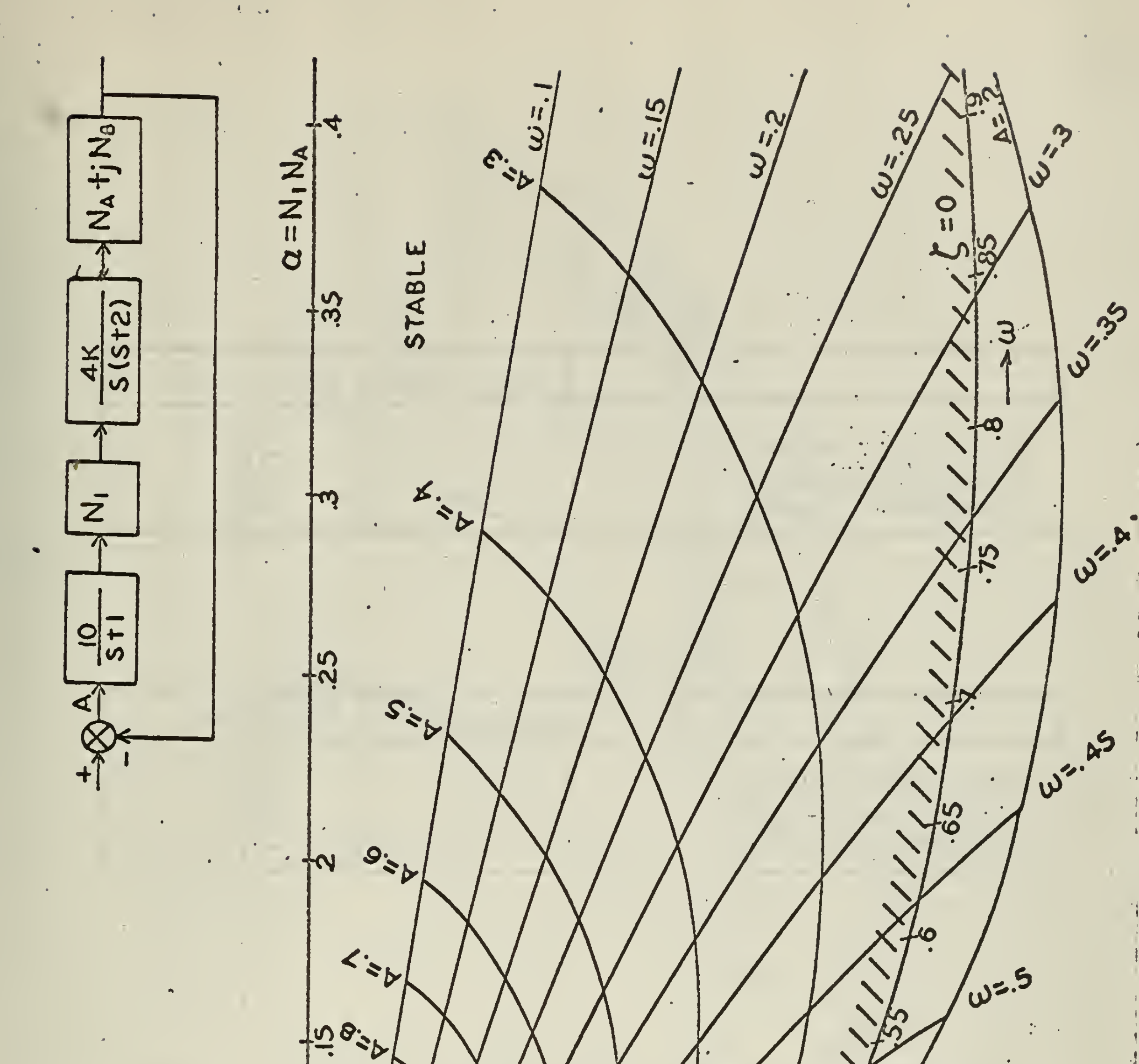


Figure II-2. Block Diagram of System Containing Saturation and Friction Controlled Backlash.



Parameter Plane Diagram K = .15

Figure II -3

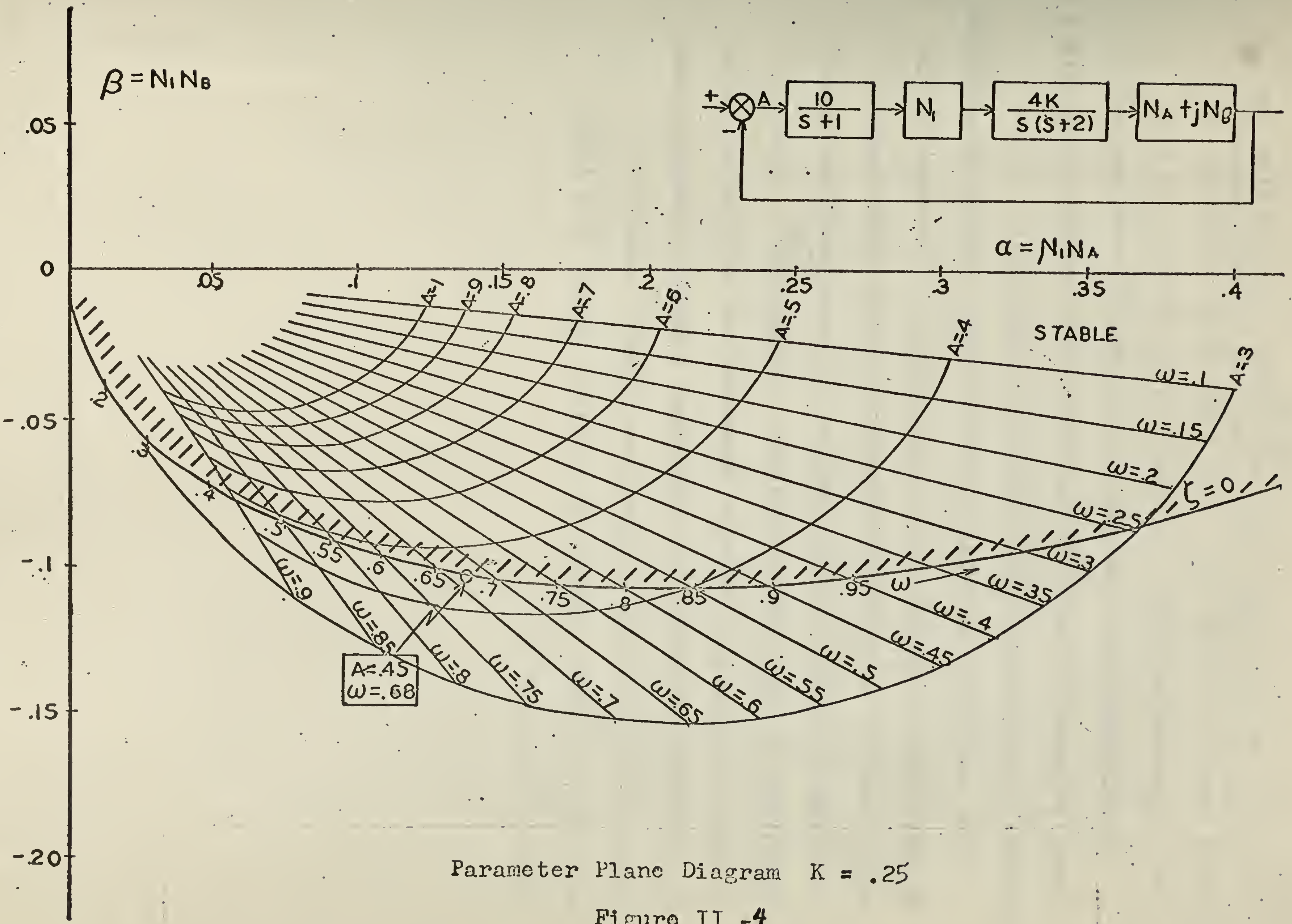
K = .15

	Amplitude	Frequency
Schirings Method	.7	.51
Analog Computer	.8	.49
Parameter Plane	.61	.52

K = .25

	Amplitude	Frequency
Schirings Method	.9	.69
Analog Computer	1.0	.65
Parameter Plane	.82	.68

Table II-1 Comparison of Limit Cycle Determination by three different methods.



Parameter Plane Diagram K = .25

Figure II -4

to get the correct limit cycle amplitude. This yields the values shown in table II-1. The limit cycle frequency is correct as determined.

Considering this same problem Donohue[50] obtained an analog computer solution and a graphical solution by Schiring's method[49] which gave results shown in table II-1.

The excellent correlation of the three methods demonstrates the accuracy of the parameter plane method. The example also shows that two dependent nonlinearities can be handled with a minimum of effort through the use of describing function techniques on the parameter plane. Pellegrini[48] enlarges on the above example and also shows the use of similar techniques when applied to two additional cases (1) Two nonlinear elements with identical signal excitation, and (2) Two nonlinear elements related to a common signal by a linear differential equation.

APPENDIX III

Computer Program for Generalized Describing Function

For the purpose of the computer compiler language slightly different notation is used than that shown in Fig. 2-1. Figure III-1 shows the general nonlinear element from which a large class of nonlinearities may be constructed. Figure II-2 shows some of the possible nonlinearities which may be used and typical values to be entered on data cards.

When using the program it is important to reduce the general nonlinearity in a logical manner to fit the nonlinearity for which data is desired. Care must be exercised so as not to introduce coordinate points which will result in the computation of a negative slope, such as entering a value of C greater than B.

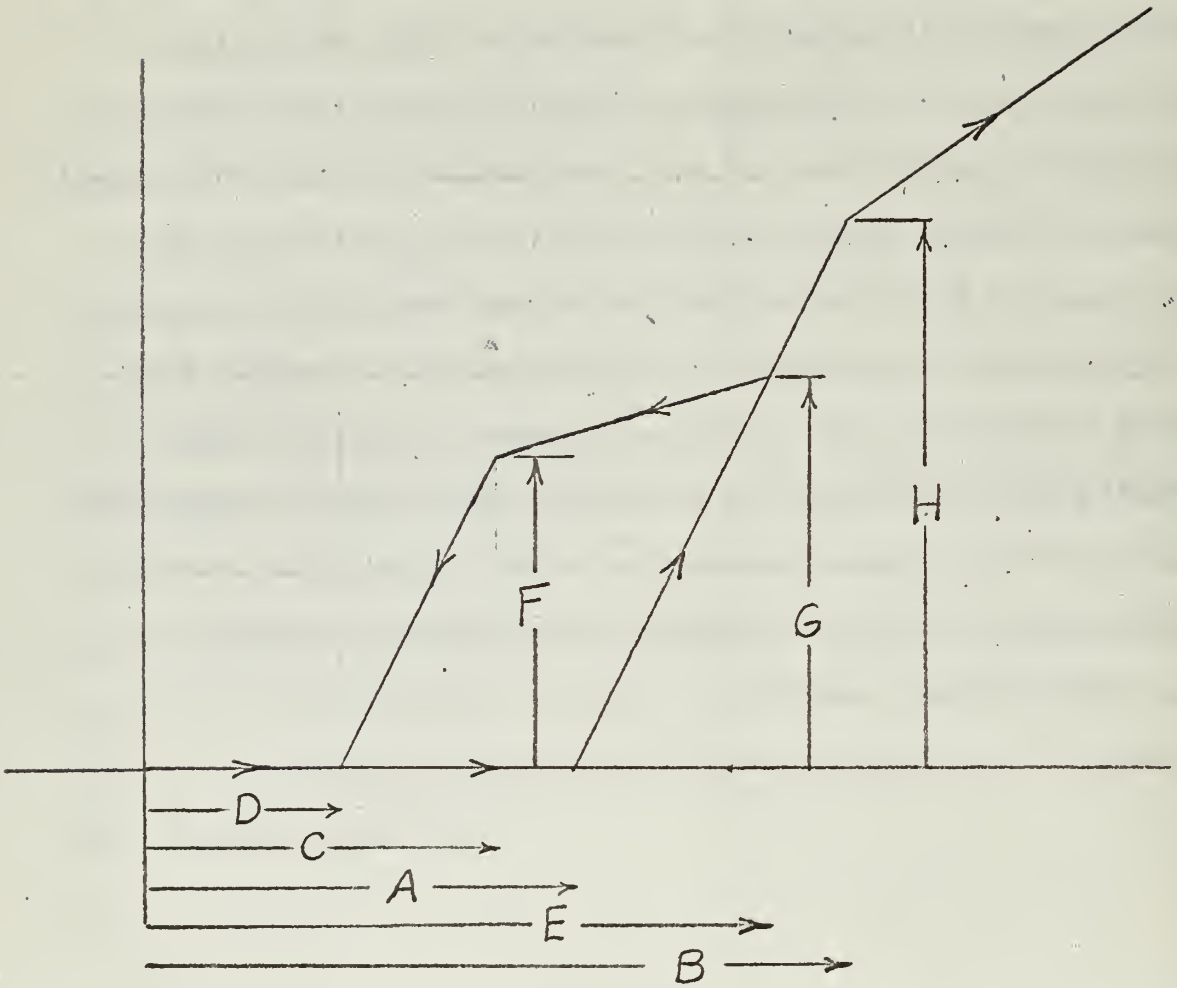
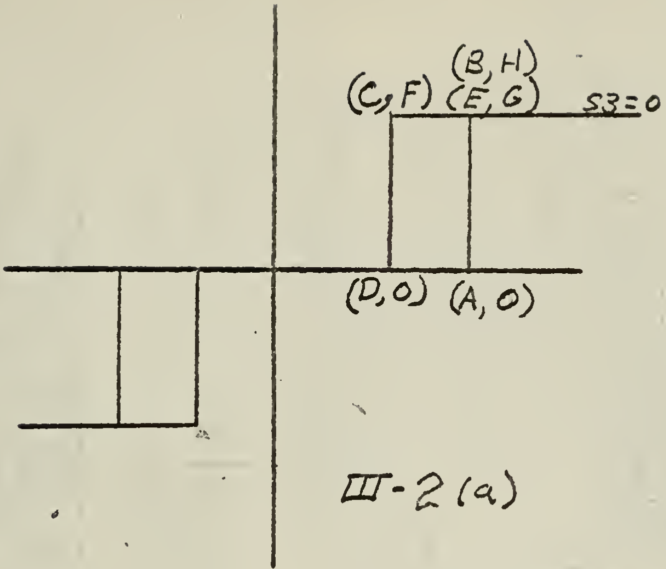


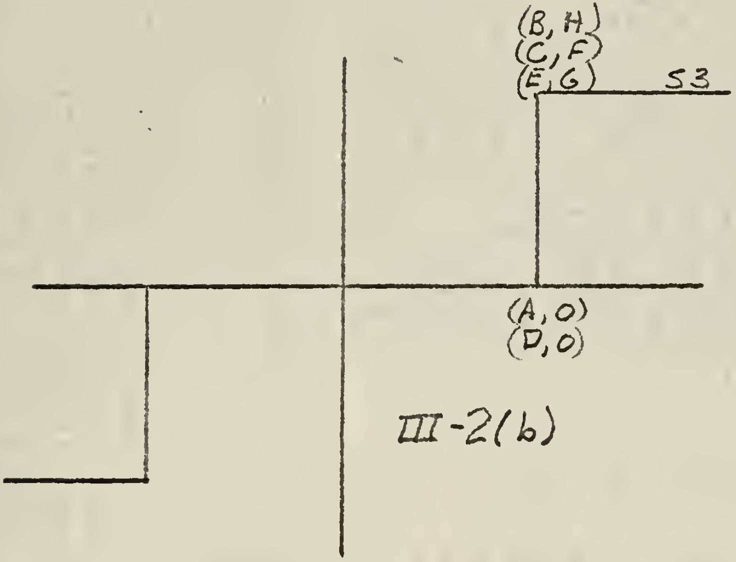
FIGURE III-1. GENERAL NONLINEAR ELEMENT FOR COMPUTER PROGRAM.



III-2(a)

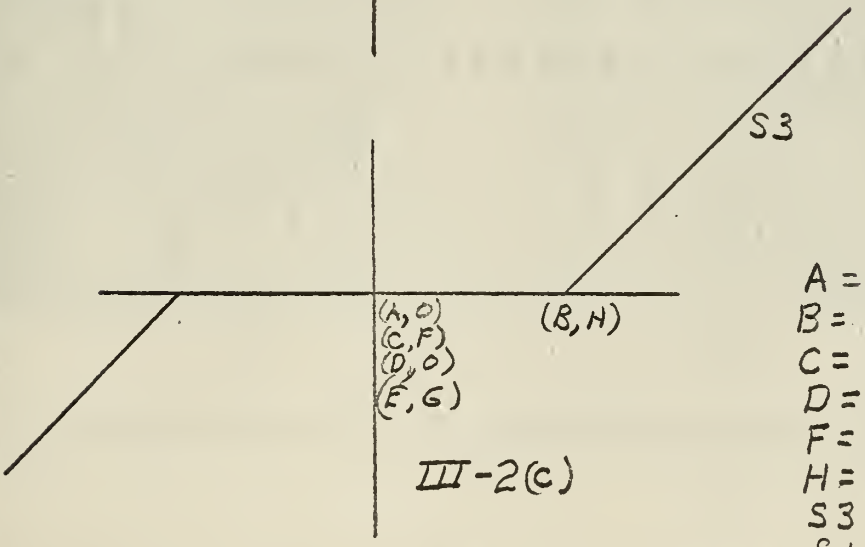
DATA ENTRIES.

A = 1.0
B = 1.0
C = .6
D = .6
E = 1.0
F = 1.0
G = 1.0
H = 1.0
S3 = 0.0
S2 = 0.0
S1 = 1.E+15



III-2(b)

A = 1.0
B = C = E = 1.0
F = G = H = 1.0
D = 1.0
S3 = 0.0
S2 = 0.
S1 = 1.E+15



III-2(c)

A = 0.0
B = 1.0
C = E = 0.0
D = 0.0
F = G = 0.0
H = 0.0
S3 = 1.0
S1 = S2 = 0.

FIGURE III-2

Examples of Nonlinearities Which May Be Handled By Program DESCRIB

```
..JOB0411F,LOVELESS  GENERAL DESCRIBING FUNCTION   E
      PROGRAM DESCRIB
C                  *                                              *
C                  *                                           *
C                  *                                     S3 *
C                  *                                     *
C                  *                                  * (B,H)
C                  *                                 *
C                  *                                *
C                  *                               *
C                  *                              *(E,G)
C                  *                           * *
C                  *                      S2*   *
C                  *                     *     *
C                  *             (C,F)*       *
C                  *                 *       *
C                  *                *       *
C                  *               *       *
C                  *            S1*     S1*
C                  *             *       *
C                  *            *       *
C                  *           *       *
C             *************************
C                  *         (D,0)   (A,0)
C                  *
C                  *
C                  *
C
C     THIS PROGRAM WILL COMPUTE THE DESCRIBING FUNCTION FOR A LARGE
C     CLASS OF NONLINEARITIES.  500 POINTS WILL BE COMPUTED AND PRINTED
C     OUT.  IN ADDITION, IF THE NONLINEARITY IS A MEMORY TYPE (HAVING
C     A HYSTERESIS OR BACKLASH LOOP WHICH HAS A PHASE SHIFT FROM INPUT
C     TO OUTPUT)  TWO GRAPHS WILL BE PLOTTED  (1) THE REAL AND IMAGINARY
C     COMPONENTS OF THE OUTPUT AND , (2) THE INVERSE DESCRIBING FUNCTION
C     -1/GD  (MAGNITUDE(DB) VS PHASE)
C        NOTE.  NO GRAPHS WILL BE PLOTTED UNLESS THE NONLINEARITY IS
```

```
C         A MEMORY FUNCTION
C       IN ORDER TO USE THE PROGRAM IS IS NECESSARY TO SPECIFY THE BREAK
C       POINTS OF THE NONLINEARITY AND ONE SLOPE.  THE GENERAL
C       NONLINEARITY IS DESCRIBED AS FOLLOWS
C
C
C
C       VALUES FOR THE X COORDINATES A,B,C,D, THE Y COORDINATES F,G,H,
C       AND THE SLOPES S1,S2,S3 MUST BE SPECIFIED
C       IF THERE IS NO HYSTERESIS LOOP, C=E, F=G (SPECIFY EQUAL VALUES
C       ON THE DATA CARDS)
C       THE PROGRAM WILL NOT RUN FOR DATA WHICH CREATES NEGATIVE SLOPES.
C
C       DATA CARDS
C         FIRST DATA CARD      THE NUMBER OF RUNS IN COLUMNS 1 AND 2
C                              RIGHT JUSTIFIED,-- THE NUMBER OF CURVES PER
C                              GRAPHS-- IN COLUMNS 3 AND 4 RIGHT
C                              JUSTIFIED.  IF NO GRAPHS ARE DESIRED LEAVE
C                              COLUMNS 3 AND 4 BLANK
C                              RIGHT JUSTIFIED
C         SECOND DATA CARD     JOB IDENTIFICATION (INCLUDING NAME)
C                              COLUMNS 1 THRU 48
C         THIRD DATA CARD.     X COORDINATES A,B,C,D
C                              FORMAT(4E20.10)
C         FOURTH DATA CARD.    X COORDINATE E,  Y COORDINATES F,G,H
C                              FORMAT(4E20.10)
C         FIFTH DATA CARD      SLOPES S1,S2,S3    FORMAT(3E20.10)
C       MULTIPLE RUNS
C       FOR MULTIPLE RUNS DATA CARD ONE IS NOT REPEATED.  ALL OTHER
C       DATA CARDS MUST BE INCLUDED.  NO  BLANK CARDS BETWEEN RUNS.
C
        DIMENSION         R(900),GD(900),DB(900),PHASE(900),THETA(900),
       1ITITLE(12),JTITLE(12),        X(900),Y(900),DBPHI(900),
       2AA(50),BB(50),CC(50),DD(50),EE(50),FF(50),GG(50),HH(50),SS1(50),
       3SS2(50),SS3(50)
        READ 1, NRUNS,LRUNDO
```

```
    1 FORMAT(2I2)
      IRUNS=0
   90 CONTINUE
      READ 100,(ITITLE(I),I=7,12)
  100 FORMAT(6A8)
      DO 101 I=7,12
      JTITLE(I)=ITITLE(I)
  101 CONTINUE
      I=IRUNS+1
      READ 10, AA(I),BB(I),CC(I),DD(I),EE(I),FF(I),GG(I),HH(I),SS1(I),
     1SS2(I),SS3(I)
   10 FORMAT(4E20.10)
      A=AA(I)
      B=BB(I)
      C=CC(I)
      D=DD(I)
      E=EE(I)
      F=FF(I)
      G=GG(I)
      H=HH(I)
      S1=SS1(I)
      S2=SS2(I)
      S3=SS3(I)
      PRINT 50,I
   50 FORMAT(1H1////, 25HINPUT DATA FOR RUN NUMBER, I4,///,11X,1HA,19X,
     11HB, 19X,1HC, 19X,1HD/)
      PRINT 10, A,B,C,D
      PRINT 51
   51 FORMAT(////, 11X,1HE, 19X,1HF, 19X, 1HG, 19X, 1HH/)
      PRINT 10,E,F,G,H
      PRINT 52
   52 FORMAT(////, 11X,2HS1, 18X,2HS2, 18X, 2HS3/)
      PRINT 10, S1,S2,S3
      IF(C-D)2,4,4
    4 IF(E-A) 2,7,7
    7 IF(E-C) 2,8,8
```

```
 8 IF(G-F) 2,9,9
 9 IF(S3) 2,15,15
 2 PRINT 6
 6 FORMAT(1H1, 45HINPUT COORDINATE POINT IS WRONG RESULTING IN ,
  1/, 14HNEGATIVE SLOPE//)
   GO TO 500
15 CONTINUE
   XX=1.
   DO 400 I=1,100
   R(I)=XX
   XIN=1./R(I)
   XX=XX-.01
   IF(B)  12,13,12
12 IF(B-E) 2,16,16
16 IF(B-A) 2,17,17
17 IF(E-A) 2,22,22
22 A=A/B
   C=C/B
   D=D/B
   E=E/B
   B=1.
   T2=ASINF(B*R(I))
   GO TO 14
13 A=A/E
   T2=3.14159/2.
14 T1=ASINF(A*R(I))
   T3=ASINF(C*R(I))
   T4=ASINF(D*R(I))
   T5=ASINF(E*R(I))
   IF(S1-1.E+4) 61,62,62
61 CONTINUE
   X(I)=S1/3.1416*(-T1+2.*T2+T3-T4-T5 +.5*(SINF(2.*T1)-2.*SINF(2.*T2)
  1-SINF(2.*T3)+SINF(2.*T4)+SINF(2.*T5))+2.*A/XIN *(-COSF(T1)+2.*
  2COSF(T2)-COSF(T5))+2.*D/XIN *(COSF(T3)-COSF(T4)))+S2/3.1416 *
  3( T5-T3+.5*(SINF(2.*T3)-SINF(2.*T5))) + 2./(3.1416*XIN )*(S2*C-F)
  4*(COSF(T5)-COSF(T3))+S3/3.1416 *(3.1416 -2.*T2+ SINF(2.*T2))
```

```
     5-4./(3.1416*XIN )*(B*S3-H) *COSF(T2)
      Y(I)=S1/3.1416*(.5*(COSF(2.*T1)+COSF(2.*T3)-COSF(2.*T4)
     1-COSF(2.*T5)) +2./(XIN **2)*(A*(A-E)+D*(C-D)))+S2/6.2832*
     2(-COSF(2.*T3)+COSF(2.*T5))+2. /(3.1416*(XIN **2))*(S2*C-F)*(E-C)
      GO TO 69
   62 X(I)=S2/3.14159*
     1( T5-T3+.5*(SINF(2.*T3)-SINF(2.*T5))) + 2./(3.1416*XIN )*(S2*C-F)
     2*(COSF(T5)-COSF(T3))+S3/3.1416 *(3.1416 -2.*T2+ SINF(2.*T2))
     3-4./(3.1416*XIN )*(B*S3-H) *COSF(T2)
      Y(I)=  S2/(2.*3.14159)*
     1(-COSF(2.*T3)+COSF(2.*T5))+2. /(3.1416*(XIN **2))*(S2*C-F)*(E-C)
   69 GD(I)=SQRTF(X(I)**2 +Y(I)**2)
      IF(GD(I)) 21,21,20
   20 DB(I)=20.*LOG10F(1./GD(I))
   21 PHASE(I)=ATANF(Y(I)/X(I))*180./3.1416
      THETA(I)=-(180.+PHASE(I))
      DBPHI(I)=THETA(I)+180.
  400 CONTINUE
      I=0
      DO 38 K=1,2
      IF(E-C) 31,39,31
   31 PRINT 35
   35 FORMAT(1H1//)
      PRINT 30,(ITITLE(I),I=7,12)
   30 FORMAT(30X,6A8,//,    17X,1HR,8X,4HREAL,6X,4HIMAG,6X,2HGD,
     17X,5HPHASE,2X,8H1/GD(DB),5X,5HTHETA/)
      DO 36 N=1,5
      DO 37 KK=1,10
      I=I+1
      PRINT 32,R(I),X(I),Y(I),GD(I),PHASE(I),DB(I),THETA(I)
   32 FORMAT(10X,4F10.4,F10.2,F10.4,F10.2)
   37 CONTINUE
      PRINT 45
   36 CONTINUE
   38 CONTINUE
      ITITLE(1)=8H
      ITITLE(2)=8HREAL AND
      ITITLE(3)=8H IMAGINA
      ITITLE(4)=8HRY COMPO
      ITITLE(5)=8HNENTS
      ITITLE(6)=8H
      JTITLE(1)=8H
      JTITLE(2)=8HMAGNITUD
      JTITLE(3)=8HE (DB) A
      JTITLE(4)=8HND PHASE
      JTITLE(5)=8H
      JTITLE(6)=8H
      LABEL = 4H
      KRUN=KRUN+1
      IF(LRUNDO-1)  60,109,116
  116 IF(KRUN-1) 110,111,110
  111 MODCURV=1
      GO TO 119
  110 IF(KRUN-LRUNDO) 113,112,112
  113 MODCURV=2
      GO TO 119
  112 MODCURV=3
      GO TO 119
  109 MODCURV=0
  119 CONTINUE
      CALL DRAW(100,  X, Y,     MODCURV, 0, LABEL, ITITLE,   0.,0.,
     10,0,0,0,8,8,0,LAST)
      IF(MODCURV)1966,1965,1966
 1965 CALL DRAW(100,DBPHI, DB,  MODCURV, 0, LABEL, JTITLE,  30.,6.,
     10,0,0,0,8,8,0,LAST)
 1966 CONTINUE
      GO TO 60
   39 N=0
      PRINT 41
   41 FORMAT(1H1//)
      PRINT 40,(ITITLE(I),I=7,12)
   40 FORMAT(30X,6A8,//,    17X,1HR,8X,2HGD,4X,8H1/GD(DB), 12X, 1HR,
   18X, 2HGD, 4X, 8H1/GD(DB)/)
    DO 46 KK=1,5
    DO 47 KL=1,10
    N=N+1
    L=N+50
    PRINT 42, R(N),GD(N),DB(N),  R(L),GD(L),DB(L)
 42 FORMAT(10X, 3F10.4,5X, 3F10.4)
 47 CONTINUE
    PRINT 45
 45 FORMAT(1H )
 46 CONTINUE
 60 CONTINUE
    IRUNS = IRUNS + 1
    IF(NRUNS-IRUNS) 500,500,90
500 IF(LRUNDO-1) 501,501,502
502 CONTINUE
    DO 1501 K=1,NRUNS
    XX=1.
    I=K
    A=AA(I)
    B=BB(I)
    C=CC(I)
    D=DD(I)
    E=EE(I)
    F=FF(I)
    G=GG(I)
    H=HH(I)
    S1=SS1(I)
    S2=SS2(I)
    S3=SS3(I)
    DO 1400 I=1,100
    R(I)=XX
    XIN=1./R(I)
    XX=XX-.01
    IF(B) 912,913,912
912 T2=ASINF(B*R(I))
```

```
     GO TO 914
 913 T2=3.14159/2.
 914 T1=ASINF(A*R(I))

     T3=ASINF(C*R(I))
     T4=ASINF(D*R(I))
     T5=ASINF(E*R(I))
     IF(S1-1.E+4) 961,962,962
 961 CONTINUE
     X(I)=S1/3.1416*(-T1+2.*T2+T3-T4-T5 +.5*(SINF(2.*T1)-2.*SINF(2.*T2)
    1-SINF(2.*T3)+SINF(2.*T4)+SINF(2.*T5))+2.*A/XIN *(-COSF(T1)+2.*
    2COSF(T2)-COSF(T5))+2.*D/XIN *(COSF(T3)-COSF(T4)))+S2/3.1416 *
    3( T5-T3+.5*(SINF(2.*T3)-SINF(2.*T5))) + 2./(3.1416*XIN )*(S2*C-F)
    4*(COSF(T5)-COSF(T3))+S3/3.1416 *(3.1416 -2.*T2+ SINF(2.*T2))
    5-4./(3.1416*XIN )*(B*S3-H) *COSF(T2)
     Y(I)=S1/3.1416*(.5*(COSF(2.*T1)+COSF(2.*T3)-COSF(2.*T4)
    1-COSF(2.*T5)) +2./(XIN **2)*(A*(A-E)+D*(C-D)))+S2/6.2832*
    2(-COSF(2.*T3)+COSF(2.*T5))+2. /(3.1416*(XIN **2))*(S2*C-F)*(E-C)
     GO TO 969
 962 X(I)=S2/3.14159*
    1( T5-T3+.5*(SINF(2.*T3)-SINF(2.*T5))) + 2./(3.1416*XIN )*(S2*C-F)
    2*(COSF(T5)-COSF(T3))+S3/3.1416 *(3.1416 -2.*T2+ SINF(2.*T2))
    3-4./(3.1416*XIN )*(B*S3-H) *COSF(T2)
     Y(I)=  S2/(2.*3.14159)*
    1(-COSF(2.*T3)+COSF(2.*T5))+2. /(3.1416*(XIN **2))*(S2*C-F)*(E-C)
 969 GD(I)=SQRTF(X(I)**2 +Y(I)**2)
     IF(GD(I)) 921,921,920
 920 DB(I)=20.*LOG10F(1./GD(I))
 921 PHASE(I)=ATANF(Y(I)/X(I))*180./3.1416
     THETA(I)=-(180.+PHASE(I))
     DBPHI(I)=THETA(I)+180.
1400 CONTINUE
1116 IF(K-1) 1110,1111,1110
1111 MODCURV=1
     GO TO 1119
1110 IF(  K -LRUNDO) 1113,1112,1112
```

```
1113 MODCURV=2
     GO TO 1119
1112 MODCURV=3
1119 CONTINUE
     CALL DRAW(100,DBPHI, DB,  MODCURV, 0, LABEL, JTITLE,  30.,6.,
    10,0,0,0,8,8,0,LAST)
1501 CONTINUE
 501 CONTINUE
     END
     END
```

```
                    GENERAL NONLINEARITY      LOVELESS

   R          REAL         IMAG          GD          PHASE   1/GD(DB)      THETA


1.0000       .8901       -.1783        .9078       -11.32      .8405     -168.68
 .9980       .8913       -.1775        .9088       -11.27      .8303     -168.73
 .9960       .8924       -.1768        .9098       -11.21      .8215     -168.79
 .9940       .8934       -.1761        .9106       -11.15      .8135     -168.85
 .9920       .8943       -.1754        .9114       -11.10      .8061     -168.90
 .9900       .8952       -.1747        .9121       -11.04      .7994     -168.96
 .9880       .8960       -.1740        .9127       -10.99      .7931     -169.01
 .9860       .8968       -.1733        .9133       -10.94      .7873     -169.06
 .9840       .8975       -.1726        .9139       -10.89      .7819     -169.11
 .9820       .8981       -.1719        .9144       -10.83      .7769     -169.17

 .9800       .8988       -.1712        .9149       -10.78      .7722     -169.22
 .9780       .8994       -.1705        .9154       -10.73      .7679     -169.27
 .9760       .8999       -.1698        .9158       -10.68      .7638     -169.32
 .9740       .9005       -.1691        .9162       -10.64      .7601     -169.36
 .9720       .9010       -.1684        .9166       -10.59      .7566     -169.41
 .9700       .9014       -.1677        .9169       -10.54      .7534     -169.46
 .9680       .9019       -.1670        .9172       -10.49      .7505     -169.51
 .9660       .9023       -.1663        .9175       -10.45      .7478     -169.55
 .9640       .9027       -.1656        .9178       -10.40      .7454     -169.60
 .9620       .9031       -.1650        .9180       -10.35      .7431     -169.65

 .9600       .9034       -.1643        .9182       -10.31      .7411     -169.69
 .9580       .9037       -.1636        .9184       -10.26      .7393     -169.74
 .9560       .9040       -.1629        .9186       -10.22      .7377     -169.78
 .9540       .9043       -.1622        .9187       -10.17      .7363     -169.83
 .9520       .9045       -.1616        .9188       -10.13      .7351     -169.87
 .9500       .9048       -.1609        .9190       -10.08      .7341     -169.92
 .9480       .9050       -.1602        .9190       -10.04      .7333     -169.96
 .9460       .9052       -.1595        .9191        -9.99      .7326     -170.01
 .9440       .9053       -.1588        .9192        -9.95      .7322     -170.05
 .9420       .9055       -.1582        .9192        -9.91      .7318     -170.09

 .9400       .9056       -.1575        .9192        -9.87      .7317     -170.13
 .9380       .9057       -.1568        .9192        -9.82      .7317     -170.18
 .9360       .9058       -.1562        .9192        -9.78      .7319     -170.22
 .9340       .9059       -.1555        .9192        -9.74      .7322     -170.26
 .9320       .9060       -.1548        .9191        -9.70      .7327     -170.30
 .9300       .9060       -.1542        .9190        -9.66      .7334     -170.34
 .9280       .9060       -.1535        .9190        -9.62      .7342     -170.38
 .9260       .9061       -.1528        .9189        -9.58      .7351     -170.42
 .9240       .9060       -.1522        .9187        -9.53      .7362     -170.47
 .9220       .9060       -.1515        .9186        -9.49      .7374     -170.51

 .9200       .9060       -.1509        .9185        -9.45      .7387     -170.55
 .9180       .9059       -.1502        .9183        -9.41      .7402     -170.59
 .9160       .9059       -.1496        .9181        -9.38      .7418     -170.62
 .9140       .9058       -.1489        .9180        -9.34      .7435     -170.66
 .9120       .9057       -.1483        .9178        -9.30      .7454     -170.70
 .9100       .9056       -.1476        .9176        -9.26      .7474     -170.74
 .9080       .9055       -.1470        .9173        -9.22      .7495     -170.78
 .9060       .9053       -.1463        .9171        -9.18      .7518     -170.82
 .9040       .9052       -.1457        .9168        -9.14      .7541     -170.86
 .9020       .9050       -.1450        .9166        -9.10      .7566     -170.90
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GENERAL NONLINEARITY LOVELESS

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.9000	.9049	-.1444	.9163	-9.07	.7592	-170.93
.8980	.9047	-.1437	.9160	-9.03	.7619	-170.97
.8960	.9045	-.1431	.9157	-8.99	.7647	-171.01
.8940	.9043	-.1425	.9154	-8.95	.7677	-171.05
.8920	.9040	-.1418	.9151	-8.92	.7707	-171.08
.8900	.9038	-.1412	.9148	-8.88	.7739	-171.12
.8880	.9035	-.1406	.9144	-8.84	.7772	-171.16
.8860	.9033	-.1399	.9141	-8.81	.7805	-171.19
.8840	.9030	-.1393	.9137	-8.77	.7840	-171.23
.8820	.9027	-.1387	.9133	-8.73	.7876	-171.27
.8800	.9024	-.1380	.9129	-8.70	.7913	-171.30
.8780	.9021	-.1374	.9125	-8.66	.7951	-171.34
.8760	.9018	-.1368	.9121	-8.63	.7990	-171.37
.8740	.9015	-.1362	.9117	-8.59	.8030	-171.41
.8720	.9011	-.1355	.9113	-8.55	.8071	-171.45
.8700	.9008	-.1349	.9108	-8.52	.8113	-171.48
.8680	.9004	-.1343	.9104	-8.48	.8156	-171.52
.8660	.9000	-.1337	.9099	-8.45	.8200	-171.55
.8640	.8997	-.1331	.9094	-8.41	.8245	-171.59
.8620	.8993	-.1324	.9090	-8.38	.8291	-171.62
.8600	.8989	-.1318	.9085	-8.34	.8338	-171.66
.8580	.8984	-.1312	.9080	-8.31	.8386	-171.69
.8560	.8980	-.1306	.9075	-8.28	.8434	-171.72
.8540	.8976	-.1300	.9069	-8.24	.8484	-171.76
.8520	.8971	-.1294	.9064	-8.21	.8534	-171.79
.8500	.8967	-.1288	.9059	-8.17	.8586	-171.83
.8480	.8962	-.1282	.9053	-8.14	.8638	-171.86
.8460	.8957	-.1276	.9048	-8.11	.8692	-171.89
.8440	.8953	-.1270	.9042	-8.07	.8746	-171.93
.8420	.8948	-.1264	.9036	-8.04	.8801	-171.96
.8400	.8943	-.1258	.9031	-8.01	.8857	-171.99
.8380	.8937	-.1252	.9025	-7.97	.8913	-172.03
.8360	.8932	-.1246	.9019	-7.94	.8971	-172.06
.8340	.8927	-.1240	.9013	-7.91	.9029	-172.09
.8320	.8922	-.1234	.9007	-7.87	.9089	-172.13
.8300	.8916	-.1228	.9000	-7.84	.9149	-172.16
.8280	.8911	-.1222	.8994	-7.81	.9210	-172.19
.8260	.8905	-.1216	.8988	-7.78	.9272	-172.22
.8240	.8899	-.1210	.8981	-7.74	.9334	-172.26
.8220	.8893	-.1204	.8975	-7.71	.9398	-172.29
.8200	.8887	-.1199	.8968	-7.68	.9462	-172.32
.8180	.8881	-.1193	.8961	-7.65	.9527	-172.35
.8160	.8875	-.1187	.8954	-7.62	.9593	-172.38
.8140	.8869	-.1181	.8947	-7.59	.9660	-172.41
.8120	.8863	-.1175	.8941	-7.55	.9727	-172.45
.8100	.8857	-.1170	.8934	-7.52	.9796	-172.48
.8080	.8850	-.1164	.8926	-7.49	.9865	-172.51
.8060	.8844	-.1158	.8919	-7.46	.9935	-172.54
.8040	.8837	-.1152	.8912	-7.43	1.0005	-172.57
.8020	.8831	-.1147	.8905	-7.40	1.0077	-172.60

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                 GENERAL NONLINEARITY      LOVELESS

  R          REAL       IMAG        GD        PHASE   1/GD(DB)     THETA

.8000       .8824     -.1141      .8897      -7.37     1.0149    -172.63
.7980       .8817     -.1135      .8890      -7.34     1.0222    -172.66
.7960       .8810     -.1129      .8882      -7.31     1.0296    -172.69
.7940       .8803     -.1124      .8875      -7.27     1.0370    -172.73
.7920       .8796     -.1118      .8867      -7.24     1.0446    -172.76
.7900       .8789     -.1112      .8859      -7.21     1.0522    -172.79
.7880       .8782     -.1107      .8851      -7.18     1.0598    -172.82
.7860       .8775     -.1101      .8843      -7.15     1.0676    -172.85
.7840       .8767     -.1096      .8835      -7.12     1.0754    -172.88
.7820       .8760     -.1090      .8827      -7.09     1.0833    -172.91

.7800       .8752     -.1084      .8819      -7.06     1.0913    -172.94
.7780       .8745     -.1079      .8811      -7.03     1.0994    -172.97
.7760       .8737     -.1073      .8803      -7.00     1.1075    -173.00
.7740       .8730     -.1068      .8795      -6.97     1.1157    -173.03
.7720       .8722     -.1062      .8786      -6.94     1.1240    -173.06
.7700       .8714     -.1057      .8778      -6.92     1.1323    -173.08
.7680       .8706     -.1051      .8769      -6.89     1.1407    -173.11
.7660       .8698     -.1046      .8761      -6.86     1.1492    -173.14
.7640       .8690     -.1040      .8752      -6.83     1.1578    -173.17
.7620       .8682     -.1035      .8743      -6.80     1.1664    -173.20

.7600       .8674     -.1030      .8735      -6.77     1.1751    -173.23
.7580       .8665     -.1024      .8726      -6.74     1.1839    -173.26
.7560       .8657     -.1019      .8717      -6.71     1.1927    -173.29
.7540       .8649     -.1013      .8708      -6.68     1.2016    -173.32
.7520       .8640     -.1008      .8699      -6.65     1.2106    -173.35
.7500       .8632     -.1003      .8690      -6.63     1.2197    -173.37
.7480       .8623     -.0997      .8681      -6.60     1.2288    -173.40
.7460       .8615     -.0992      .8672      -6.57     1.2380    -173.43
.7440       .8606     -.0987      .8662      -6.54     1.2473    -173.46
.7420       .8597     -.0981      .8653      -6.51     1.2566    -173.49

.7400       .8588     -.0976      .8644      -6.48     1.2660    -173.52
.7380       .8579     -.0971      .8634      -6.46     1.2755    -173.54
.7360       .8571     -.0966      .8625      -6.43     1.2850    -173.57
.7340       .8562     -.0960      .8615      -6.40     1.2947    -173.60
.7320       .8552     -.0955      .8606      -6.37     1.3043    -173.63
.7300       .8543     -.0950      .8596      -6.34     1.3141    -173.66
.7280       .8534     -.0945      .8586      -6.32     1.3239    -173.68
.7260       .8525     -.0940      .8577      -6.29     1.3338    -173.71
.7240       .8516     -.0934      .8567      -6.26     1.3438    -173.74
.7220       .8506     -.0929      .8557      -6.23     1.3538    -173.77

.7200       .8497     -.0924      .8547      -6.21     1.3639    -173.79
.7180       .8487     -.0919      .8537      -6.18     1.3740    -173.82
.7160       .8478     -.0914      .8527      -6.15     1.3842    -173.85
.7140       .8468     -.0909      .8517      -6.13     1.3945    -173.87
.7120       .8458     -.0904      .8507      -6.10     1.4049    -173.90
.7100       .8449     -.0899      .8496      -6.07     1.4153    -173.93
.7080       .8439     -.0894      .8486      -6.04     1.4258    -173.96
.7060       .8429     -.0888      .8476      -6.02     1.4364    -173.98
.7040       .8419     -.0883      .8465      -5.99     1.4470    -174.01
.7020       .8409     -.0878      .8455      -5.96     1.4577    -174.04
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                         GENERAL NONLINEARITY        LOVELESS

     R          REAL         IMAG          GD          PHASE   1/GD(DB)        THETA


   .7000       .8399        -.0873        .8445        -5.94     1.4685       -174.06
   .6980       .8389        -.0868        .8434        -5.91     1.4793       -174.09
   .6960       .8379        -.0863        .8423        -5.88     1.4902       -174.12
   .6940       .8369        -.0859        .8413        -5.86     1.5012       -174.14
   .6920       .8359        -.0854        .8402        -5.83     1.5122       -174.17
   .6900       .8348        -.0849        .8391        -5.80     1.5233       -174.20
   .6880       .8338        -.0844        .8381        -5.78     1.5344       -174.22
   .6860       .8328        -.0839        .8370        -5.75     1.5457       -174.25
   .6840       .8317        -.0834        .8359        -5.73     1.5569       -174.27
   .6820       .8307        -.0829        .8348        -5.70     1.5683       -174.30

   .6800       .8296        -.0824        .8337        -5.67     1.5797       -174.33
   .6780       .8286        -.0819        .8326        -5.65     1.5912       -174.35
   .6760       .8275        -.0815        .8315        -5.62     1.6028       -174.38
   .6740       .8264        -.0810        .8304        -5.60     1.6144       -174.40
   .6720       .8254        -.0805        .8293        -5.57     1.6261       -174.43
   .6700       .8243        -.0800        .8281        -5.54     1.6378       -174.46
   .6680       .8232        -.0795        .8270        -5.52     1.6496       -174.48
   .6660       .8221        -.0791        .8259        -5.49     1.6615       -174.51
   .6640       .8210        -.0786        .8248        -5.47     1.6735       -174.53
   .6620       .8199        -.0781        .8236        -5.44     1.6855       -174.56

   .6600       .8188        -.0776        .8225        -5.42     1.6976       -174.58
   .6580       .8177        -.0772        .8213        -5.39     1.7097       -174.61
   .6560       .8166        -.0767        .8202        -5.37     1.7219       -174.63
   .6540       .8155        -.0762        .8190        -5.34     1.7342       -174.66
   .6520       .8143        -.0758        .8179        -5.32     1.7465       -174.68
   .6500       .8132        -.0753        .8167        -5.29     1.7589       -174.71
   .6480       .8121        -.0748        .8155        -5.27     1.7714       -174.73
   .6460       .8109        -.0744        .8143        -5.24     1.7839       -174.76
   .6440       .8098        -.0739        .8132        -5.22     1.7965       -174.78
   .6420       .8086        -.0735        .8120        -5.19     1.8092       -174.81

   .6400       .8075        -.0730        .8108        -5.17     1.8219       -174.83
   .6380       .8063        -.0726        .8096        -5.14     1.8347       -174.86
   .6360       .8052        -.0721        .8084        -5.12     1.8476       -174.88
   .6340       .8040        -.0716        .8072        -5.09     1.8605       -174.91
   .6320       .8028        -.0712        .8060        -5.07     1.8735       -174.93
   .6300       .8017        -.0707        .8048        -5.04     1.8865       -174.96
   .6280       .8005        -.0703        .8036        -5.02     1.8997       -174.98
   .6260       .7993        -.0699        .8023        -4.99     1.9128       -175.01
   .6240       .7981        -.0694        .8011        -4.97     1.9261       -175.03
   .6220       .7969        -.0690        .7999        -4.95     1.9394       -175.05

   .6200       .7957        -.0685        .7987        -4.92     1.9528       -175.08
   .6180       .7945        -.0681        .7974        -4.90     1.9662       -175.10
   .6160       .7933        -.0676        .7962        -4.87     1.9797       -175.13
   .6140       .7921        -.0672        .7949        -4.85     1.9933       -175.15
   .6120       .7909        -.0668        .7937        -4.83     2.0070       -175.17
   .6100       .7897        -.0663        .7924        -4.80     2.0207       -175.20
   .6080       .7884        -.0659        .7912        -4.78     2.0344       -175.22
   .6060       .7872        -.0655        .7899        -4.75     2.0483       -175.25
   .6040       .7860        -.0650        .7887        -4.73     2.0622       -175.27
   .6020       .7847        -.0646        .7874        -4.71     2.0762       -175.29
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                 GENERAL NONLINEARITY      LOVELESS

  R          REAL        IMAG          GD          PHASE   1/GD(DB)      THETA

.6000       .7835       -.0642        .7861        -4.68    2.0902     -175.32
.5980       .7823       -.0637        .7848        -4.66    2.1043     -175.34
.5960       .7810       -.0633        .7836        -4.63    2.1184     -175.37
.5940       .7798       -.0629        .7823        -4.61    2.1327     -175.39
.5920       .7785       -.0625        .7810        -4.59    2.1470     -175.41
.5900       .7772       -.0620        .7797        -4.56    2.1613     -175.44
.5880       .7760       -.0616        .7784        -4.54    2.1758     -175.46
.5860       .7747       -.0612        .7771        -4.52    2.1903     -175.48
.5840       .7734       -.0608        .7758        -4.49    2.2048     -175.51
.5820       .7722       -.0604        .7745        -4.47    2.2194     -175.53

.5800       .7709       -.0600        .7732        -4.45    2.2341     -175.55
.5780       .7696       -.0596        .7719        -4.42    2.2489     -175.58
.5760       .7683       -.0591        .7706        -4.40    2.2637     -175.60
.5740       .7670       -.0587        .7693        -4.38    2.2786     -175.62
.5720       .7657       -.0583        .7679        -4.36    2.2936     -175.64
.5700       .7644       -.0579        .7666        -4.33    2.3086     -175.67
.5680       .7631       -.0575        .7653        -4.31    2.3237     -175.69
.5660       .7618       -.0571        .7639        -4.29    2.3388     -175.71
.5640       .7605       -.0567        .7626        -4.26    2.3541     -175.74
.5620       .7592       -.0563        .7613        -4.24    2.3693     -175.76

.5600       .7579       -.0559        .7599        -4.22    2.3847     -175.78
.5580       .7565       -.0555        .7586        -4.20    2.4001     -175.80
.5560       .7552       -.0551        .7572        -4.17    2.4156     -175.83
.5540       .7539       -.0547        .7559        -4.15    2.4312     -175.85
.5520       .7525       -.0543        .7545        -4.13    2.4468     -175.87
.5500       .7512       -.0539        .7531        -4.11    2.4625     -175.89
.5480       .7499       -.0535        .7518        -4.08    2.4782     -175.92
.5460       .7485       -.0531        .7504        -4.06    2.4941     -175.94
.5440       .7472       -.0528        .7490        -4.04    2.5100     -175.96
.5420       .7458       -.0524        .7477        -4.02    2.5259     -175.98

.5400       .7445       -.0520        .7463        -3.99    2.5420     -176.01
.5380       .7431       -.0516        .7449        -3.97    2.5580     -176.03
.5360       .7417       -.0512        .7435        -3.95    2.5742     -176.05
.5340       .7404       -.0508        .7421        -3.93    2.5904     -176.07
.5320       .7390       -.0504        .7407        -3.91    2.6067     -176.09
.5300       .7376       -.0501        .7393        -3.88    2.6231     -176.12
.5280       .7363       -.0497        .7379        -3.86    2.6396     -176.14
.5260       .7349       -.0493        .7365        -3.84    2.6561     -176.16
.5240       .7335       -.0489        .7351        -3.82    2.6726     -176.18
.5220       .7321       -.0486        .7337        -3.80    2.6893     -176.20

.5200       .7307       -.0482        .7323        -3.77    2.7060     -176.23
.5180       .7293       -.0478        .7309        -3.75    2.7228     -176.25
.5160       .7279       -.0475        .7295        -3.73    2.7396     -176.27
.5140       .7265       -.0471        .7281        -3.71    2.7566     -176.29
.5120       .7251       -.0467        .7266        -3.69    2.7735     -176.31
.5100       .7237       -.0464        .7252        -3.67    2.7906     -176.33
.5080       .7223       -.0460        .7238        -3.64    2.8077     -176.36
.5060       .7209       -.0456        .7224        -3.62    2.8249     -176.38
.5040       .7195       -.0453        .7209        -3.60    2.8422     -176.40
.5020       .7181       -.0449        .7195        -3.58    2.8596     -176.42
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                    GENERAL NONLINEARITY     LOVELESS

   R          REAL       IMAG        GD        PHASE   1/GD(DB)     THETA

 .5000       .7167     -.0446      .7180      -3.56     2.8770     -176.44
 .4980       .7152     -.0442      .7166      -3.54     2.8945     -176.46
 .4960       .7138     -.0439      .7152      -3.52     2.9120     -176.48
 .4940       .7124     -.0435      .7137      -3.49     2.9296     -176.51
 .4920       .7109     -.0431      .7123      -3.47     2.9473     -176.53
 .4900       .7095     -.0428      .7108      -3.45     2.9651     -176.55
 .4880       .7081     -.0424      .7093      -3.43     2.9829     -176.57
 .4860       .7066     -.0421      .7079      -3.41     3.0008     -176.59
 .4840       .7052     -.0418      .7064      -3.39     3.0188     -176.61
 .4820       .7037     -.0414      .7049      -3.37     3.0369     -176.63

 .4800       .7023     -.0411      .7035      -3.35     3.0550     -176.65
 .4780       .7008     -.0407      .7020      -3.33     3.0732     -176.67
 .4760       .6994     -.0404      .7005      -3.31     3.0915     -176.69
 .4740       .6979     -.0400      .6991      -3.28     3.1098     -176.72
 .4720       .6964     -.0397      .6976      -3.26     3.1282     -176.74
 .4700       .6950     -.0394      .6961      -3.24     3.1467     -176.76
 .4680       .6935     -.0390      .6946      -3.22     3.1653     -176.78
 .4660       .6920     -.0387      .6931      -3.20     3.1839     -176.80
 .4640       .6906     -.0384      .6916      -3.18     3.2026     -176.82
 .4620       .6891     -.0380      .6901      -3.16     3.2214     -176.84

 .4600       .6876     -.0377      .6886      -3.14     3.2403     -176.86
 .4580       .6861     -.0374      .6871      -3.12     3.2592     -176.88
 .4560       .6846     -.0371      .6856      -3.10     3.2782     -176.90
 .4540       .6831     -.0367      .6841      -3.08     3.2973     -176.92
 .4520       .6816     -.0364      .6826      -3.06     3.3165     -176.94
 .4500       .6802     -.0361      .6811      -3.04     3.3357     -176.96
 .4480       .6787     -.0358      .6796      -3.02     3.3550     -176.98
 .4460       .6772     -.0355      .6781      -3.00     3.3744     -177.00
 .4440       .6756     -.0351      .6766      -2.98     3.3938     -177.02
 .4420       .6741     -.0348      .6750      -2.96     3.4134     -177.04

 .4400       .6726     -.0345      .6735      -2.94     3.4330     -177.06
 .4380       .6711     -.0342      .6720      -2.92     3.4527     -177.08
 .4360       .6696     -.0339      .6705      -2.90     3.4724     -177.10
 .4340       .6681     -.0336      .6689      -2.88     3.4923     -177.12
 .4320       .6666     -.0333      .6674      -2.86     3.5122     -177.14
 .4300       .6651     -.0330      .6659      -2.84     3.5322     -177.16
 .4280       .6635     -.0327      .6643      -2.82     3.5523     -177.18
 .4260       .6620     -.0323      .6628      -2.80     3.5724     -177.20
 .4240       .6605     -.0320      .6613      -2.78     3.5926     -177.22
 .4220       .6589     -.0317      .6597      -2.76     3.6130     -177.24

 .4200       .6574     -.0314      .6582      -2.74     3.6333     -177.26
 .4180       .6559     -.0311      .6566      -2.72     3.6538     -177.28
 .4160       .6543     -.0308      .6551      -2.70     3.6744     -177.30
 .4140       .6528     -.0306      .6535      -2.68     3.6950     -177.32
 .4120       .6512     -.0303      .6520      -2.66     3.7157     -177.34
 .4100       .6497     -.0300      .6504      -2.64     3.7365     -177.36
 .4080       .6482     -.0297      .6488      -2.62     3.7573     -177.38
 .4060       .6466     -.0294      .6473      -2.60     3.7783     -177.40
 .4040       .6450     -.0291      .6457      -2.58     3.7993     -177.42
 .4020       .6435     -.0288      .6441      -2.56     3.8204     -177.44
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GENERAL NONLINEARITY LOVELESS

```
   R          REAL        IMAG         GD          PHASE   1/GD(DB)      THETA

.4000        .6419      -.0285       .6426       -2.54     3.8416     -177.46
.3980        .6404      -.0282       .6410       -2.52     3.8629     -177.48
.3960        .6388      -.0280       .6394       -2.51     3.8842     -177.49
.3940        .6372      -.0277       .6378       -2.49     3.9057     -177.51
.3920        .6357      -.0274       .6363       -2.47     3.9272     -177.53
.3900        .6341      -.0271       .6347       -2.45     3.9488     -177.55
.3880        .6325      -.0268       .6331       -2.43     3.9705     -177.57
.3860        .6310      -.0266       .6315       -2.41     3.9922     -177.59
.3840        .6294      -.0263       .6299       -2.39     4.0141     -177.61
.3820        .6278      -.0260       .6283       -2.37     4.0360     -177.63

.3800        .6262      -.0257       .6268       -2.35     4.0581     -177.65
.3780        .6246      -.0255       .6252       -2.33     4.0802     -177.67
.3760        .6231      -.0252       .6236       -2.32     4.1024     -177.68
.3740        .6215      -.0249       .6220       -2.30     4.1246     -177.70
.3720        .6199      -.0247       .6204       -2.28     4.1470     -177.72
.3700        .6183      -.0244       .6188       -2.26     4.1694     -177.74
.3680        .6167      -.0241       .6172       -2.24     4.1920     -177.76
.3660        .6151      -.0239       .6156       -2.22     4.2146     -177.78
.3640        .6135      -.0236       .6140       -2.20     4.2373     -177.80
.3620        .6119      -.0234       .6123       -2.19     4.2601     -177.81

.3600        .6103      -.0231       .6107       -2.17     4.2830     -177.83
.3580        .6087      -.0228       .6091       -2.15     4.3060     -177.85
.3560        .6071      -.0226       .6075       -2.13     4.3290     -177.87
.3540        .6055      -.0223       .6059       -2.11     4.3522     -177.89
.3520        .6039      -.0221       .6043       -2.09     4.3754     -177.91
.3500        .6023      -.0218       .6026       -2.08     4.3987     -177.92
.3480        .6006      -.0216       .6010       -2.06     4.4222     -177.94
.3460        .5990      -.0213       .5994       -2.04     4.4457     -177.96
.3440        .5974      -.0211       .5978       -2.02     4.4693     -177.98
.3420        .5958      -.0208       .5961       -2.00     4.4930     -178.00

.3400        .5942      -.0206       .5945       -1.99     4.5168     -178.01
.3380        .5925      -.0204       .5929       -1.97     4.5406     -178.03
.3360        .5909      -.0201       .5912       -1.95     4.5646     -178.05
.3340        .5893      -.0199       .5896       -1.93     4.5887     -178.07
.3320        .5876      -.0196       .5880       -1.91     4.6128     -178.09
.3300        .5860      -.0194       .5863       -1.90     4.6371     -178.10
.3280        .5844      -.0192       .5847       -1.88     4.6614     -178.12
.3260        .5827      -.0189       .5831       -1.86     4.6859     -178.14
.3240        .5811      -.0187       .5814       -1.84     4.7104     -178.16
.3220        .5795      -.0185       .5798       -1.83     4.7350     -178.17

.3200        .5778      -.0183       .5781       -1.81     4.7597     -178.19
.3180        .5762      -.0180       .5765       -1.79     4.7846     -178.21
.3160        .5745      -.0178       .5748       -1.77     4.8095     -178.23
.3140        .5729      -.0176       .5732       -1.76     4.8345     -178.24
.3120        .5712      -.0174       .5715       -1.74     4.8596     -178.26
.3100        .5696      -.0171       .5698       -1.72     4.8848     -178.28
.3080        .5679      -.0169       .5682       -1.71     4.9101     -178.29
.3060        .5663      -.0167       .5665       -1.69     4.9355     -178.31
.3040        .5646      -.0165       .5649       -1.67     4.9610     -178.33
.3020        .5630      -.0163       .5632       -1.65     4.9866     -178.35
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                        GENERAL NONLINEARITY      LOVELESS

      R          REAL        IMAG         GD          PHASE   1/GD(DB)      THETA


    .3000       .5613      -.0160       .5615        -1.64     5.0124     -178.36
    .2980       .5597      -.0158       .5599        -1.62     5.0382     -178.38
    .2960       .5580      -.0156       .5582        -1.60     5.0641     -178.40
    .2940       .5563      -.0154       .5565        -1.59     5.0901     -178.41
    .2920       .5547      -.0152       .5549        -1.57     5.1162     -178.43
    .2900       .5530      -.0150       .5532        -1.55     5.1424     -178.45
    .2880       .5513      -.0148       .5515        -1.54     5.1687     -178.46
    .2860       .5497      -.0146       .5498        -1.52     5.1952     -178.48
    .2840       .5480      -.0144       .5482        -1.50     5.2217     -178.50
    .2820       .5463      -.0142       .5465        -1.49     5.2483     -178.51

    .2800       .5446      -.0140       .5448        -1.47     5.2751     -178.53
    .2780       .5430      -.0138       .5431        -1.45     5.3019     -178.55
    .2760       .5413      -.0136       .5414        -1.44     5.3289     -178.56
    .2740       .5396      -.0134       .5398        -1.42     5.3559     -178.58
    .2720       .5379      -.0132       .5381        -1.40     5.3831     -178.60
    .2700       .5362      -.0130       .5364        -1.39     5.4104     -178.61
    .2680       .5345      -.0128       .5347        -1.37     5.4378     -178.63
    .2660       .5329      -.0126       .5330        -1.36     5.4653     -178.64
    .2640       .5312      -.0124       .5313        -1.34     5.4929     -178.66
    .2620       .5295      -.0122       .5296        -1.32     5.5206     -178.68

    .2600       .5278      -.0120       .5279        -1.31     5.5484     -178.69
    .2580       .5261      -.0119       .5262        -1.29     5.5764     -178.71
    .2560       .5244      -.0117       .5245        -1.28     5.6044     -178.72
    .2540       .5227      -.0115       .5228        -1.26     5.6326     -178.74
    .2520       .5210      -.0113       .5211        -1.24     5.6609     -178.76
    .2500       .5193      -.0111       .5194        -1.23     5.6893     -178.77
    .2480       .5176      -.0110       .5177        -1.21     5.7178     -178.79
    .2460       .5159      -.0108       .5160        -1.20     5.7464     -178.80
    .2440       .5142      -.0106       .5143        -1.18     5.7751     -178.82
    .2420       .5125      -.0104       .5126        -1.17     5.8040     -178.83

    .2400       .5108      -.0103       .5109        -1.15     5.8330     -178.85
    .2380       .5091      -.0101       .5092        -1.14     5.8621     -178.86
    .2360       .5074      -.0099       .5075        -1.12     5.8913     -178.88
    .2340       .5057      -.0098       .5058        -1.11     5.9206     -178.89
    .2320       .5040      -.0096       .5041        -1.09     5.9501     -178.91
    .2300       .5023      -.0094       .5024        -1.08     5.9796     -178.92
    .2280       .5006      -.0093       .5006        -1.06     6.0093     -178.94
    .2260       .4989      -.0091       .4989        -1.05     6.0391     -178.95
    .2240       .4971      -.0089       .4972        -1.03     6.0691     -178.97
    .2220       .4954      -.0088       .4955        -1.02     6.0992     -178.98

    .2200       .4937      -.0086       .4938        -1.00     6.1293     -179.00
    .2180       .4920      -.0085       .4921         -.99     6.1597     -179.01
    .2160       .4903      -.0083       .4903         -.97     6.1901     -179.03
    .2140       .4885      -.0082       .4886         -.96     6.2207     -179.04
    .2120       .4868      -.0080       .4869         -.94     6.2514     -179.06
    .2100       .4851      -.0079       .4852         -.93     6.2822     -179.07
    .2080       .4834      -.0077       .4834         -.91     6.3132     -179.09
    .2060       .4817      -.0076       .4817         -.90     6.3442     -179.10
    .2040       .4799      -.0074       .4800         -.89     6.3755     -179.11
    .2020       .4782      -.0073       .4783         -.87     6.4068     -179.13
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                 GENERAL NONLINEARITY      LOVELESS

  R          REAL        IMAG         GD          PHASE   1/GD(DB)     THETA

.2000       .4765      -.0071       .4765         -.86     6.4383     -179.14
.1980       .4747      -.0070       .4748         -.84     6.4699     -179.16
.1960       .4730      -.0068       .4731         -.83     6.5016     -179.17
.1940       .4713      -.0067       .4713         -.82     6.5335     -179.18
.1920       .4695      -.0066       .4696         -.80     6.5656     -179.20
.1900       .4678      -.0064       .4679         -.79     6.5977     -179.21
.1880       .4661      -.0063       .4661         -.77     6.6300     -179.23
.1860       .4643      -.0062       .4644         -.76     6.6624     -179.24
.1840       .4626      -.0060       .4626         -.75     6.6950     -179.25
.1820       .4609      -.0059       .4609         -.73     6.7277     -179.27

.1800       .4591      -.0058       .4592         -.72     6.7606     -179.28
.1780       .4574      -.0056       .4574         -.71     6.7936     -179.29
.1760       .4557      -.0055       .4557         -.69     6.8267     -179.31
.1740       .4539      -.0054       .4539         -.68     6.8600     -179.32
.1720       .4522      -.0053       .4522         -.67     6.8934     -179.33
.1700       .4504      -.0052       .4505         -.66     6.9270     -179.34
.1680       .4487      -.0050       .4487         -.64     6.9607     -179.36
.1660       .4469      -.0049       .4470         -.63     6.9946     -179.37
.1640       .4452      -.0048       .4452         -.62     7.0286     -179.38
.1620       .4434      -.0047       .4435         -.60     7.0628     -179.40

.1600       .4417      -.0046       .4417         -.59     7.0971     -179.41
.1580       .4399      -.0044       .4400         -.58     7.1316     -179.42
.1560       .4382      -.0043       .4382         -.57     7.1662     -179.43
.1540       .4364      -.0042       .4365         -.55     7.2010     -179.45
.1520       .4347      -.0041       .4347         -.54     7.2360     -179.46
.1500       .4329      -.0040       .4330         -.53     7.2711     -179.47
.1480       .4312      -.0039       .4312         -.52     7.3063     -179.48
.1460       .4294      -.0038       .4295         -.51     7.3417     -179.49
.1440       .4277      -.0037       .4277         -.50     7.3773     -179.50
.1420       .4259      -.0036       .4259         -.48     7.4130     -179.52

.1400       .4242      -.0035       .4242         -.47     7.4489     -179.53
.1380       .4224      -.0034       .4224         -.46     7.4850     -179.54
.1360       .4207      -.0033       .4207         -.45     7.5212     -179.55
.1340       .4189      -.0032       .4189         -.44     7.5576     -179.56
.1320       .4171      -.0031       .4171         -.43     7.5942     -179.57
.1300       .4154      -.0030       .4154         -.42     7.6309     -179.58
.1280       .4136      -.0029       .4136         -.40     7.6678     -179.60
.1260       .4119      -.0028       .4119         -.39     7.7049     -179.61
.1240       .4101      -.0027       .4101         -.38     7.7421     -179.62
.1220       .4083      -.0027       .4083         -.37     7.7796     -179.63

.1200       .4066      -.0026       .4066         -.36     7.8171     -179.64
.1180       .4048      -.0025       .4048         -.35     7.8549     -179.65
.1160       .4030      -.0024       .4030         -.34     7.8929     -179.66
.1140       .4013      -.0023       .4013         -.33     7.9310     -179.67
.1120       .3995      -.0022       .3995         -.32     7.9693     -179.68
.1100       .3977      -.0022       .3978         -.31     8.0078     -179.69
.1080       .3960      -.0021       .3960         -.30     8.0465     -179.70
.1060       .3942      -.0020       .3942         -.29     8.0853     -179.71
.1040       .3924      -.0019       .3924         -.28     8.1244     -179.72
.1020       .3907      -.0019       .3907         -.27     8.1636     -179.73
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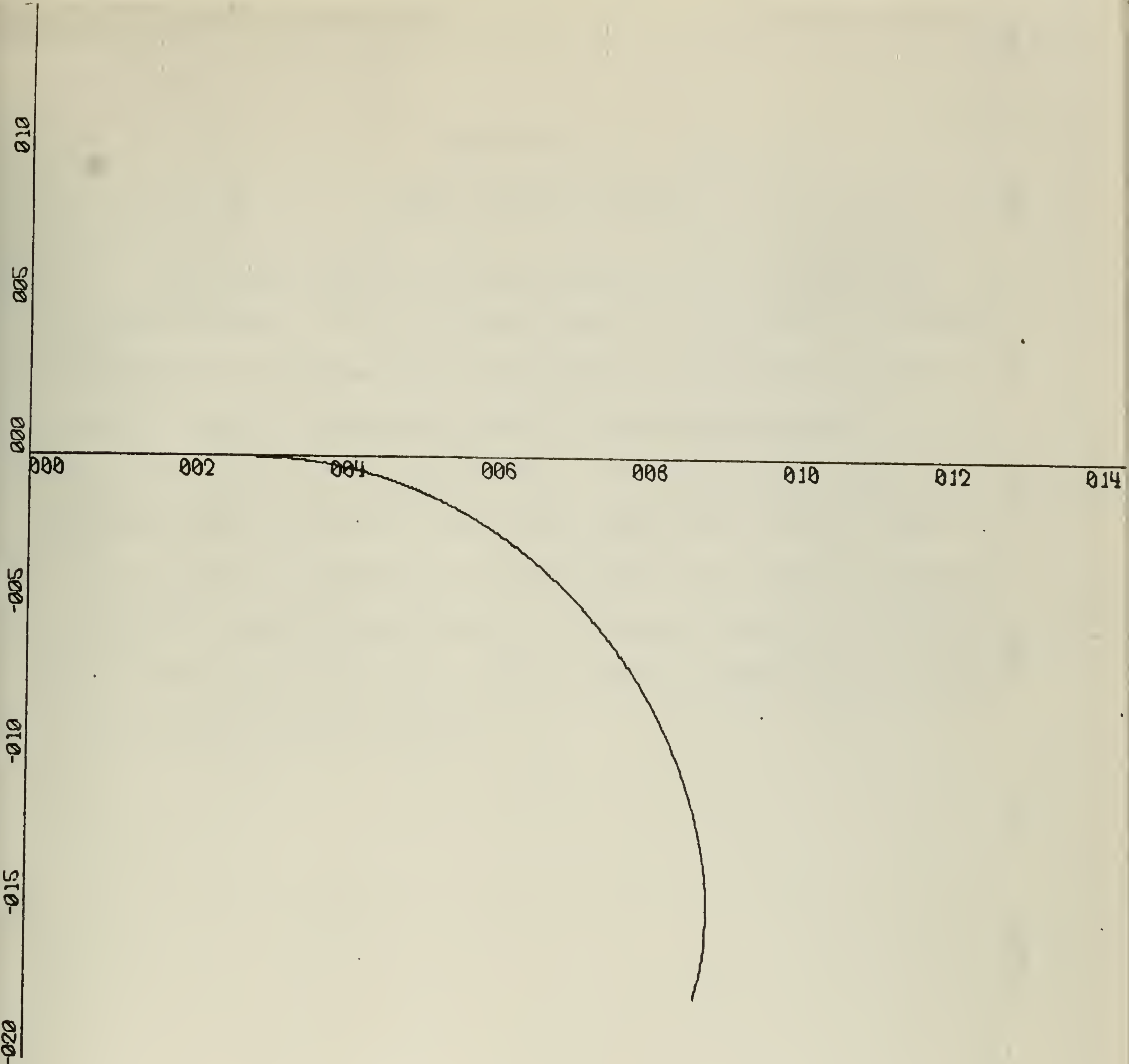
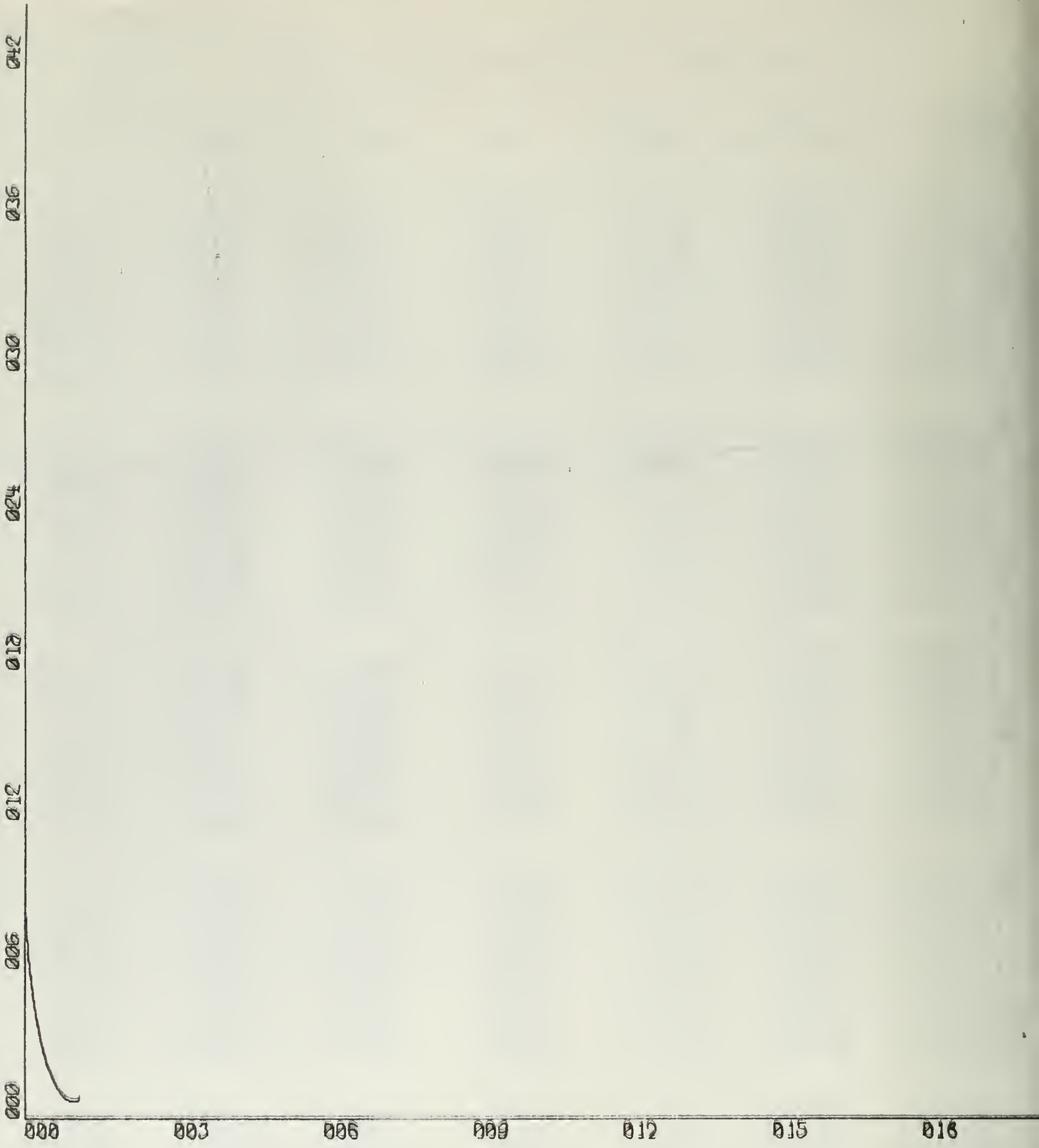
GENERAL NONLINEARITY LOVELESS

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.1000	.3889	-.0018	.3889	-.26	8.2030	-179.74
.0980	.3871	-.0017	.3871	-.25	8.2427	-179.75
.0960	.3854	-.0016	.3854	-.24	8.2825	-179.76
.0940	.3836	-.0016	.3836	-.24	8.3225	-179.76
.0920	.3818	-.0015	.3818	-.23	8.3627	-179.77
.0900	.3801	-.0014	.3801	-.22	8.4031	-179.78
.0880	.3783	-.0014	.3783	-.21	8.4437	-179.79
.0860	.3765	-.0013	.3765	-.20	8.4845	-179.80
.0840	.3747	-.0013	.3747	-.19	8.5255	-179.81
.0820	.3730	-.0012	.3730	-.18	8.5667	-179.82
.0800	.3712	-.0011	.3712	-.18	8.6081	-179.82
.0780	.3694	-.0011	.3694	-.17	8.6497	-179.83
.0760	.3676	-.0010	.3676	-.16	8.6915	-179.84
.0740	.3659	-.0010	.3659	-.15	8.7336	-179.85
.0720	.3641	-.0009	.3641	-.15	8.7758	-179.85
.0700	.3623	-.0009	.3623	-.14	8.8183	-179.86
.0680	.3605	-.0008	.3605	-.13	8.8610	-179.87
.0660	.3588	-.0008	.3588	-.12	8.9039	-179.88
.0640	.3570	-.0007	.3570	-.12	8.9470	-179.88
.0620	.3552	-.0007	.3552	-.11	8.9904	-179.89
.0600	.3534	-.0006	.3534	-.10	9.0340	-179.90
.0580	.3517	-.0006	.3517	-.10	9.0778	-179.90
.0560	.3499	-.0006	.3499	-.09	9.1218	-179.91
.0540	.3481	-.0005	.3481	-.09	9.1661	-179.91
.0520	.3463	-.0005	.3463	-.08	9.2106	-179.92
.0500	.3445	-.0004	.3445	-.07	9.2553	-179.93
.0480	.3428	-.0004	.3428	-.07	9.3003	-179.93
.0460	.3410	-.0004	.3410	-.06	9.3455	-179.94
.0440	.3392	-.0003	.3392	-.06	9.3910	-179.94
.0420	.3374	-.0003	.3374	-.05	9.4367	-179.95
.0400	.3356	-.0003	.3356	-.05	9.4826	-179.95
.0380	.3339	-.0003	.3339	-.04	9.5288	-179.96
.0360	.3321	-.0002	.3321	-.04	9.5753	-179.96
.0340	.3303	-.0002	.3303	-.04	9.6220	-179.96
.0320	.3285	-.0002	.3285	-.03	9.6689	-179.97
.0300	.3267	-.0002	.3267	-.03	9.7162	-179.97
.0280	.3250	-.0001	.3250	-.02	9.7637	-179.98
.0260	.3232	-.0001	.3232	-.02	9.8114	-179.98
.0240	.3214	-.0001	.3214	-.02	9.8594	-179.98
.0220	.3196	-.0001	.3196	-.02	9.9077	-179.98
.0200	.3178	-.0001	.3178	-.01	9.9563	-179.99
.0180	.3160	-.0001	.3160	-.01	10.0051	-179.99
.0160	.3143	-.0000	.3143	-.01	10.0542	-179.99
.0140	.3125	-.0000	.3125	-.01	10.1036	-179.99
.0120	.3107	-.0000	.3107	-.00	10.1533	-180.00
.0100	.3089	-.0000	.3089	-.00	10.2033	-180.00
.0080	.3071	-.0000	.3071	-.00	10.2536	-180.00
.0060	.3053	-.0000	.3053	-.00	10.3041	-180.00
.0040	.3036	-.0000	.3036	-.00	10.3550	-180.00
.0020	.3018	-.0000	.3018	-.00	10.4061	-180.00



X-SCALE = 2.00E-01 UNITS/INCH.
Y-SCALE = 5.00E-02 UNITS/INCH.

REAL AND IMAGINARY COMPONENTS
GENERAL NONLINEARITY LOVELESS



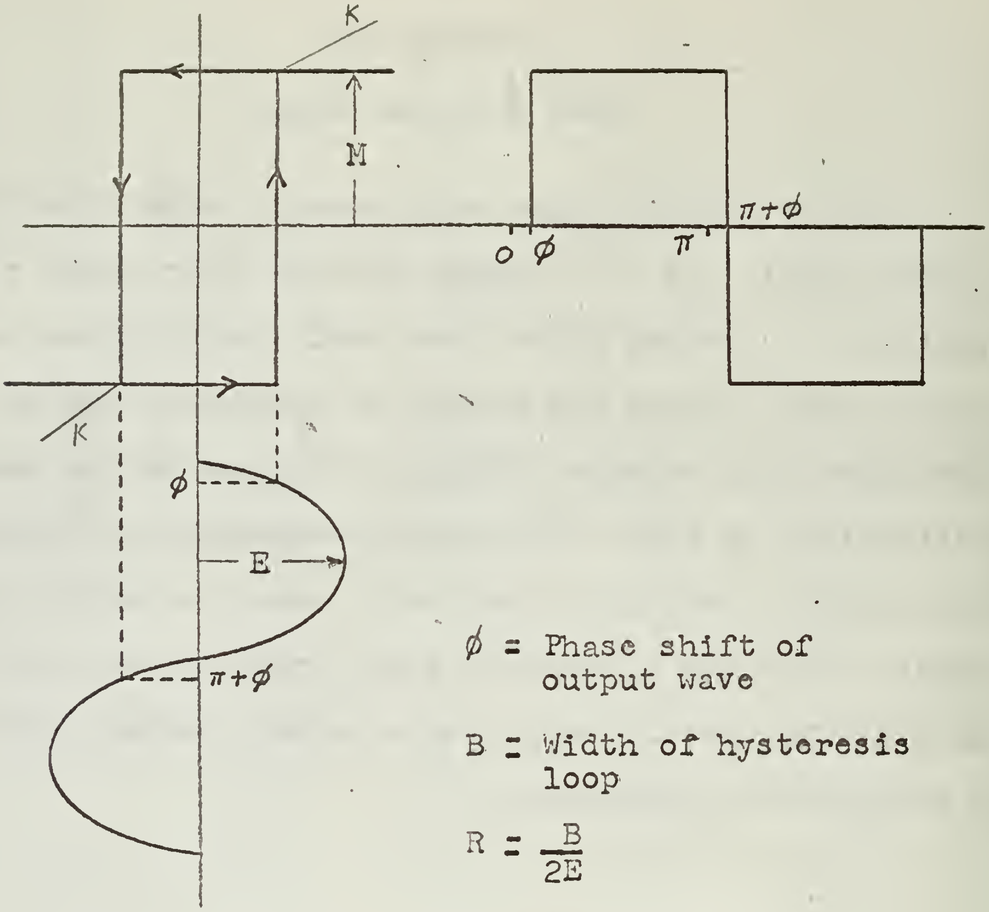
X-SCALE = 3.00E+01 UNITS/INCH.
Y-SCALE = 6.00E+00 UNITS/INCH.

MAGNITUDE (DB) AND PHASE
GENERAL NONLINEARITY LOVELESS

APPENDIX IV

Two Position Relay

This is a memory type nonlinearity which introduces a phase shift. It is a common type of relay which provides stability to systems which have small oscillations around a zero point. Often the amount of hysteresis can be controlled by a voltage setting. If a system has small oscillations an ideal relay would constantly be switching thus causing instability and even damage to driven equipment. However, with the hysteresis small input signals are ignored and switching occurs only with a command signal large enough to overcome the hysteresis.



ϕ = Phase shift of output wave

B = Width of hysteresis loop

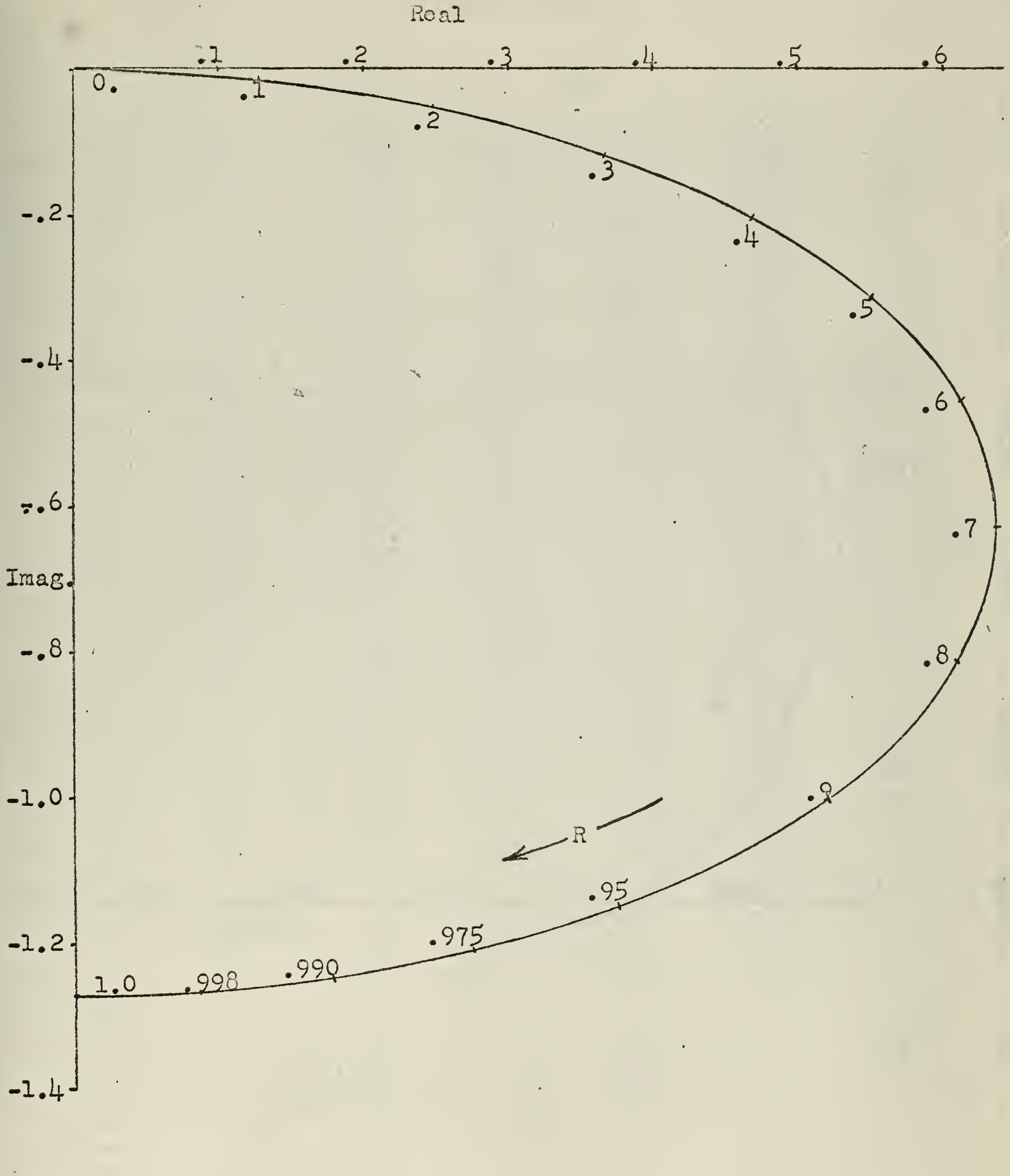
$R = \frac{B}{2E}$

*Real $= \frac{4M}{\pi E} \cos \theta_2$ *Imaginary $= -\frac{4M}{\pi E} \sin \theta_2$

$$GD = \frac{4M}{\pi E} \angle \sin^{-1} B$$

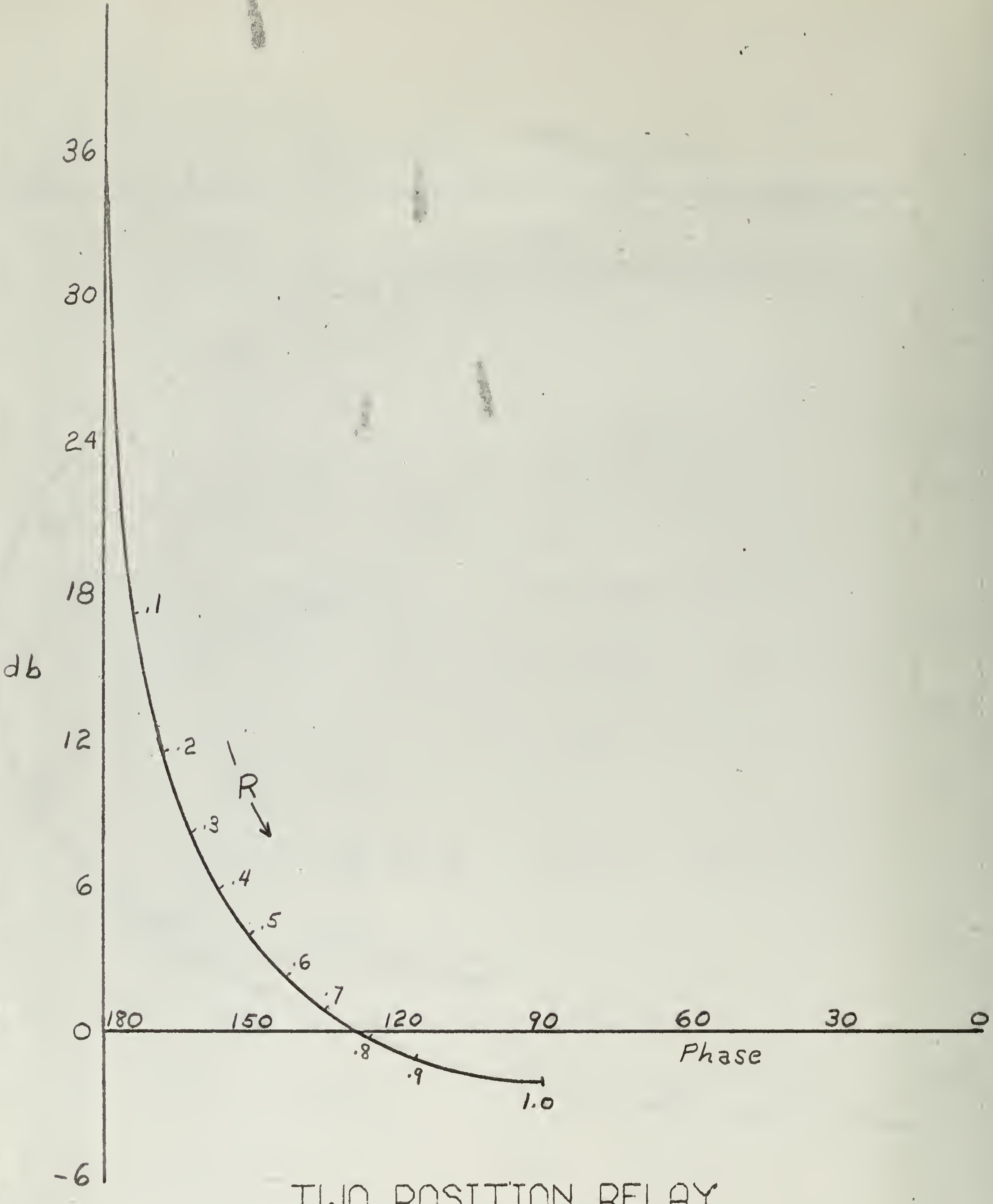
*See General Describing Function

TWO POSITION RELAY
Figure IV-1



TWO POSITION RELAY
REAL AND IMAGINARY COMPONENTS

Figure IV-2



TWO POSITION RELAY
MAGNITUDE(DB) AND PHASE

Figure IV-3

TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
1.000	.0000	-1.2732	1.2732	-90.00	-2.0982	-90.00
.998	.0803	-1.2682	1.2707	-86.38	-2.0808	-93.62
.996	.1133	-1.2631	1.2681	-84.87	-2.0634	-95.13
.994	.1384	-1.2580	1.2656	-83.72	-2.0459	-96.28
.992	.1594	-1.2530	1.2631	-82.75	-2.0284	-97.25
.990	.1778	-1.2479	1.2605	-81.89	-2.0109	-98.11
.988	.1943	-1.2429	1.2580	-81.11	-1.9933	-98.89
.986	.2093	-1.2378	1.2554	-80.40	-1.9757	-99.60
.984	.2232	-1.2328	1.2529	-79.74	-1.9581	-100.26
.982	.2362	-1.2278	1.2503	-79.11	-1.9404	-100.89
.980	.2483	-1.2228	1.2478	-78.52	-1.9227	-101.48
.978	.2598	-1.2178	1.2452	-77.96	-1.9050	-102.04
.976	.2706	-1.2129	1.2427	-77.42	-1.8872	-102.58
.974	.2810	-1.2079	1.2401	-76.91	-1.8694	-103.09
.972	.2908	-1.2029	1.2376	-76.41	-1.8515	-103.59
.970	.3002	-1.1980	1.2350	-75.93	-1.8336	-104.07
.968	.3093	-1.1931	1.2325	-75.47	-1.8157	-104.53
.966	.3180	-1.1881	1.2300	-75.02	-1.7978	-104.98
.964	.3264	-1.1832	1.2274	-74.58	-1.7798	-105.42
.962	.3344	-1.1783	1.2249	-74.15	-1.7617	-105.85
.960	.3422	-1.1734	1.2223	-73.74	-1.7436	-106.26
.958	.3498	-1.1685	1.2198	-73.34	-1.7255	-106.66
.956	.3571	-1.1637	1.2172	-72.94	-1.7074	-107.06
.954	.3642	-1.1588	1.2147	-72.55	-1.6892	-107.45
.952	.3710	-1.1539	1.2121	-72.18	-1.6709	-107.82
.950	.3777	-1.1491	1.2096	-71.81	-1.6527	-108.19
.948	.3842	-1.1443	1.2070	-71.44	-1.6344	-108.56
.946	.3905	-1.1394	1.2045	-71.08	-1.6160	-108.92
.944	.3966	-1.1346	1.2019	-70.73	-1.5976	-109.27
.942	.4025	-1.1298	1.1994	-70.39	-1.5792	-109.61
.940	.4083	-1.1250	1.1968	-70.05	-1.5608	-109.95
.938	.4140	-1.1203	1.1943	-69.72	-1.5423	-110.28
.936	.4195	-1.1155	1.1918	-69.39	-1.5237	-110.61
.934	.4249	-1.1107	1.1892	-69.07	-1.5051	-110.93
.932	.4301	-1.1060	1.1867	-68.75	-1.4865	-111.25
.930	.4352	-1.1012	1.1841	-68.43	-1.4679	-111.57
.928	.4402	-1.0965	1.1816	-68.13	-1.4492	-111.87
.926	.4451	-1.0918	1.1790	-67.82	-1.4304	-112.18
.924	.4499	-1.0871	1.1765	-67.52	-1.4116	-112.48
.922	.4545	-1.0824	1.1739	-67.22	-1.3928	-112.78
.920	.4591	-1.0777	1.1714	-66.93	-1.3740	-113.07
.918	.4635	-1.0730	1.1688	-66.64	-1.3551	-113.36
.916	.4679	-1.0683	1.1663	-66.35	-1.3361	-113.65
.914	.4721	-1.0637	1.1637	-66.06	-1.3171	-113.94
.912	.4763	-1.0590	1.1612	-65.78	-1.2981	-114.22
.910	.4804	-1.0544	1.1586	-65.51	-1.2790	-114.49
.908	.4844	-1.0497	1.1561	-65.23	-1.2599	-114.77
.906	.4883	-1.0451	1.1536	-64.96	-1.2408	-115.04
.904	.4921	-1.0405	1.1510	-64.69	-1.2216	-115.31
.902	.4958	-1.0359	1.1485	-64.42	-1.2023	-115.58

TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
.900	.4995	-1.0313	1.1459	-64.16	-1.1831	-115.84
.898	.5031	-1.0267	1.1434	-63.90	-1.1637	-116.10
.896	.5066	-1.0222	1.1408	-63.64	-1.1444	-116.36
.894	.5100	-1.0176	1.1383	-63.38	-1.1250	-116.62
.892	.5134	-1.0131	1.1357	-63.13	-1.1055	-116.87
.890	.5167	-1.0085	1.1332	-62.87	-1.0860	-117.13
.888	.5199	-1.0040	1.1306	-62.62	-1.0665	-117.38
.886	.5231	-.9995	1.1281	-62.37	-1.0469	-117.63
.884	.5262	-.9950	1.1255	-62.13	-1.0273	-117.87
.882	.5292	-.9905	1.1230	-61.88	-1.0076	-118.12
.880	.5322	-.9860	1.1205	-61.64	-.9879	-118.36
.878	.5351	-.9815	1.1179	-61.40	-.9681	-118.60
.876	.5379	-.9771	1.1154	-61.16	-.9483	-118.84
.874	.5407	-.9726	1.1128	-60.93	-.9284	-119.07
.872	.5435	-.9682	1.1103	-60.69	-.9085	-119.31
.870	.5462	-.9637	1.1077	-60.46	-.8886	-119.54
.868	.5488	-.9593	1.1052	-60.23	-.8686	-119.77
.866	.5514	-.9549	1.1026	-60.00	-.8486	-120.00
.864	.5539	-.9505	1.1001	-59.77	-.8285	-120.23
.862	.5563	-.9461	1.0975	-59.54	-.8084	-120.46
.860	.5588	-.9417	1.0950	-59.32	-.7882	-120.68
.858	.5611	-.9373	1.0924	-59.09	-.7680	-120.91
.856	.5634	-.9329	1.0899	-58.87	-.7477	-121.13
.854	.5657	-.9286	1.0873	-58.65	-.7274	-121.35
.852	.5679	-.9243	1.0848	-58.43	-.7070	-121.57
.850	.5701	-.9199	1.0823	-58.21	-.6866	-121.79
.848	.5722	-.9156	1.0797	-57.99	-.6661	-122.01
.846	.5743	-.9113	1.0772	-57.78	-.6456	-122.22
.844	.5764	-.9070	1.0746	-57.57	-.6251	-122.43
.842	.5784	-.9027	1.0721	-57.35	-.6045	-122.65
.840	.5803	-.8984	1.0695	-57.14	-.5838	-122.86
.838	.5822	-.8941	1.0670	-56.93	-.5631	-123.07
.836	.5841	-.8899	1.0644	-56.72	-.5423	-123.28
.834	.5859	-.8856	1.0619	-56.51	-.5215	-123.49
.832	.5877	-.8814	1.0593	-56.30	-.5007	-123.70
.830	.5894	-.8771	1.0568	-56.10	-.4798	-123.90
.828	.5911	-.8729	1.0542	-55.89	-.4588	-124.11
.826	.5928	-.8687	1.0517	-55.69	-.4378	-124.31
.824	.5944	-.8645	1.0492	-55.49	-.4168	-124.51
.822	.5960	-.8603	1.0466	-55.29	-.3956	-124.71
.820	.5976	-.8561	1.0441	-55.08	-.3745	-124.92
.818	.5991	-.8520	1.0415	-54.89	-.3533	-125.11
.816	.6006	-.8478	1.0390	-54.69	-.3320	-125.31
.814	.6020	-.8436	1.0364	-54.49	-.3107	-125.51
.812	.6034	-.8395	1.0339	-54.29	-.2893	-125.71
.810	.6048	-.8354	1.0313	-54.10	-.2679	-125.90
.808	.6061	-.8313	1.0288	-53.90	-.2464	-126.10
.806	.6074	-.8271	1.0262	-53.71	-.2249	-126.29
.804	.6087	-.8230	1.0237	-53.51	-.2033	-126.49
.802	.6100	-.8190	1.0211	-53.32	-.1817	-126.68

TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
.800	.6112	-.8149	1.0186	-53.13	-.1600	-126.87
.798	.6123	-.8108	1.0160	-52.94	-.1383	-127.06
.796	.6135	-.8067	1.0135	-52.75	-.1165	-127.25
.794	.6146	-.8027	1.0110	-52.56	-.0946	-127.44
.792	.6157	-.7987	1.0084	-52.37	-.0727	-127.63
.790	.6167	-.7946	1.0059	-52.19	-.0508	-127.81
.788	.6177	-.7906	1.0033	-52.00	-.0287	-128.00
.786	.6187	-.7866	1.0008	-51.81	-.0067	-128.19
.784	.6197	-.7826	.9982	-51.63	.0155	-128.37
.782	.6206	-.7786	.9957	-51.44	.0377	-128.56
.780	.6215	-.7746	.9931	-51.26	.0599	-128.74
.778	.6223	-.7707	.9906	-51.08	.0822	-128.92
.776	.6232	-.7667	.9880	-50.90	.1046	-129.10
.774	.6240	-.7628	.9855	-50.71	.1270	-129.29
.772	.6248	-.7588	.9829	-50.53	.1494	-129.47
.770	.6255	-.7549	.9804	-50.35	.1720	-129.65
.768	.6263	-.7510	.9778	-50.17	.1946	-129.83
.766	.6270	-.7471	.9753	-50.00	.2172	-130.00
.764	.6276	-.7432	.9728	-49.82	.2399	-130.18
.762	.6283	-.7393	.9702	-49.64	.2627	-130.36
.760	.6289	-.7354	.9677	-49.46	.2855	-130.54
.758	.6295	-.7316	.9651	-49.29	.3084	-130.71
.756	.6301	-.7277	.9626	-49.11	.3314	-130.89
.754	.6306	-.7239	.9600	-48.94	.3544	-131.06
.752	.6311	-.7200	.9575	-48.76	.3774	-131.24
.750	.6316	-.7162	.9549	-48.59	.4006	-131.41
.748	.6321	-.7124	.9524	-48.42	.4238	-131.58
.746	.6325	-.7086	.9498	-48.25	.4470	-131.75
.744	.6330	-.7048	.9473	-48.07	.4703	-131.93
.742	.6334	-.7010	.9447	-47.90	.4937	-132.10
.740	.6337	-.6972	.9422	-47.73	.5172	-132.27
.738	.6341	-.6935	.9397	-47.56	.5407	-132.44
.736	.6344	-.6897	.9371	-47.39	.5642	-132.61
.734	.6347	-.6860	.9346	-47.22	.5879	-132.78
.732	.6350	-.6822	.9320	-47.05	.6116	-132.95
.730	.6352	-.6785	.9295	-46.89	.6353	-133.11
.728	.6355	-.6748	.9269	-46.72	.6592	-133.28
.726	.6357	-.6711	.9244	-46.55	.6831	-133.45
.724	.6359	-.6674	.9218	-46.39	.7070	-133.61
.722	.6360	-.6637	.9193	-46.22	.7310	-133.78
.720	.6362	-.6600	.9167	-46.05	.7551	-133.95
.718	.6363	-.6564	.9142	-45.89	.7793	-134.11
.716	.6364	-.6527	.9116	-45.73	.8035	-134.27
.714	.6365	-.6491	.9091	-45.56	.8278	-134.44
.712	.6366	-.6455	.9065	-45.40	.8522	-134.60
.710	.6366	-.6418	.9040	-45.23	.8766	-134.77
.708	.6366	-.6382	.9015	-45.07	.9011	-134.93
.706	.6366	-.6346	.8989	-44.91	.9257	-135.09
.704	.6366	-.6310	.8964	-44.75	.9503	-135.25
.702	.6366	-.6275	.8938	-44.59	.9750	-135.41

TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
.700	.6365	-.6239	.8913	-44.43	.9998	-135.57
.698	.6364	-.6203	.8887	-44.27	1.0247	-135.73
.696	.6363	-.6168	.8862	-44.11	1.0496	-135.89
.694	.6362	-.6132	.8836	-43.95	1.0746	-136.05
.692	.6361	-.6097	.8811	-43.79	1.0997	-136.21
.690	.6359	-.6062	.8785	-43.63	1.1248	-136.37
.688	.6357	-.6027	.8760	-43.47	1.1500	-136.53
.686	.6355	-.5992	.8734	-43.31	1.1753	-136.69
.684	.6353	-.5957	.8709	-43.16	1.2007	-136.84
.682	.6351	-.5922	.8684	-43.00	1.2261	-137.00
.680	.6348	-.5887	.8658	-42.84	1.2516	-137.16
.678	.6345	-.5853	.8633	-42.69	1.2772	-137.31
.676	.6343	-.5818	.8607	-42.53	1.3029	-137.47
.674	.6340	-.5784	.8582	-42.38	1.3286	-137.62
.672	.6336	-.5750	.8556	-42.22	1.3544	-137.78
.670	.6333	-.5716	.8531	-42.07	1.3803	-137.93
.668	.6329	-.5682	.8505	-41.91	1.4063	-138.09
.666	.6326	-.5648	.8480	-41.76	1.4323	-138.24
.664	.6322	-.5614	.8454	-41.61	1.4584	-138.39
.662	.6317	-.5580	.8429	-41.45	1.4846	-138.55
.660	.6313	-.5546	.8403	-41.30	1.5109	-138.70
.658	.6309	-.5513	.8378	-41.15	1.5373	-138.85
.656	.6304	-.5479	.8352	-41.00	1.5637	-139.00
.654	.6299	-.5446	.8327	-40.84	1.5902	-139.16
.652	.6294	-.5413	.8302	-40.69	1.6168	-139.31
.650	.6289	-.5379	.8276	-40.54	1.6435	-139.46
.648	.6284	-.5346	.8251	-40.39	1.6703	-139.61
.646	.6279	-.5313	.8225	-40.24	1.6971	-139.76
.644	.6273	-.5281	.8200	-40.09	1.7241	-139.91
.642	.6267	-.5248	.8174	-39.94	1.7511	-140.06
.640	.6261	-.5215	.8149	-39.79	1.7782	-140.21
.638	.6255	-.5183	.8123	-39.64	1.8054	-140.36
.636	.6249	-.5150	.8098	-39.49	1.8326	-140.51
.634	.6243	-.5118	.8072	-39.35	1.8600	-140.65
.632	.6236	-.5086	.8047	-39.20	1.8874	-140.80
.630	.6229	-.5053	.8021	-39.05	1.9150	-140.95
.628	.6223	-.5021	.7996	-38.90	1.9426	-141.10
.626	.6216	-.4990	.7970	-38.76	1.9703	-141.24
.624	.6208	-.4958	.7945	-38.61	1.9981	-141.39
.622	.6201	-.4926	.7920	-38.46	2.0260	-141.54
.620	.6194	-.4894	.7894	-38.32	2.0540	-141.68
.618	.6186	-.4863	.7869	-38.17	2.0820	-141.83
.616	.6178	-.4831	.7843	-38.02	2.1102	-141.98
.614	.6171	-.4800	.7818	-37.88	2.1384	-142.12
.612	.6163	-.4769	.7792	-37.73	2.1668	-142.27
.610	.6154	-.4738	.7767	-37.59	2.1952	-142.41
.608	.6146	-.4707	.7741	-37.45	2.2237	-142.55
.606	.6138	-.4676	.7716	-37.30	2.2523	-142.70
.604	.6129	-.4645	.7690	-37.16	2.2811	-142.84
.602	.6120	-.4614	.7665	-37.01	2.3099	-142.99

TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
.600	.6112	-.4584	.7639	-36.87	2.3388	-143.13
.598	.6103	-.4553	.7614	-36.73	2.3678	-143.27
.596	.6093	-.4523	.7589	-36.58	2.3969	-143.42
.594	.6084	-.4492	.7563	-36.44	2.4261	-143.56
.592	.6075	-.4462	.7538	-36.30	2.4554	-143.70
.590	.6065	-.4432	.7512	-36.16	2.4848	-143.84
.588	.6056	-.4402	.7487	-36.02	2.5142	-143.98
.586	.6046	-.4372	.7461	-35.87	2.5438	-144.13
.584	.6036	-.4342	.7436	-35.73	2.5735	-144.27
.582	.6026	-.4313	.7410	-35.59	2.6033	-144.41
.580	.6016	-.4283	.7385	-35.45	2.6332	-144.55
.578	.6005	-.4254	.7359	-35.31	2.6632	-144.69
.576	.5995	-.4224	.7334	-35.17	2.6933	-144.83
.574	.5985	-.4195	.7308	-35.03	2.7236	-144.97
.572	.5974	-.4166	.7283	-34.89	2.7539	-145.11
.570	.5963	-.4137	.7257	-34.75	2.7843	-145.25
.568	.5952	-.4108	.7232	-34.61	2.8148	-145.39
.566	.5941	-.4079	.7207	-34.47	2.8455	-145.53
.564	.5930	-.4050	.7181	-34.33	2.8762	-145.67
.562	.5919	-.4021	.7156	-34.19	2.9071	-145.81
.560	.5907	-.3993	.7130	-34.06	2.9380	-145.94
.558	.5896	-.3964	.7105	-33.92	2.9691	-146.08
.556	.5884	-.3936	.7079	-33.78	3.0003	-146.22
.554	.5872	-.3908	.7054	-33.64	3.0316	-146.36
.552	.5860	-.3880	.7028	-33.50	3.0630	-146.50
.550	.5849	-.3852	.7003	-33.37	3.0945	-146.63
.548	.5836	-.3824	.6977	-33.23	3.1262	-146.77
.546	.5824	-.3796	.6952	-33.09	3.1579	-146.91
.544	.5812	-.3768	.6926	-32.96	3.1898	-147.04
.542	.5799	-.3740	.6901	-32.82	3.2218	-147.18
.540	.5787	-.3713	.6875	-32.68	3.2539	-147.32
.538	.5774	-.3685	.6850	-32.55	3.2861	-147.45
.536	.5761	-.3658	.6825	-32.41	3.3185	-147.59
.534	.5749	-.3631	.6799	-32.28	3.3510	-147.72
.532	.5736	-.3604	.6774	-32.14	3.3836	-147.86
.530	.5722	-.3577	.6748	-32.01	3.4163	-147.99
.528	.5709	-.3550	.6723	-31.87	3.4491	-148.13
.526	.5696	-.3523	.6697	-31.74	3.4821	-148.26
.524	.5682	-.3496	.6672	-31.60	3.5152	-148.40
.522	.5669	-.3469	.6646	-31.47	3.5484	-148.53
.520	.5655	-.3443	.6621	-31.33	3.5817	-148.67
.518	.5642	-.3416	.6595	-31.20	3.6152	-148.80
.516	.5628	-.3390	.6570	-31.06	3.6488	-148.94
.514	.5614	-.3364	.6544	-30.93	3.6825	-149.07
.512	.5600	-.3338	.6519	-30.80	3.7164	-149.20
.510	.5586	-.3312	.6494	-30.66	3.7504	-149.34
.508	.5571	-.3286	.6468	-30.53	3.7845	-149.47
.506	.5557	-.3260	.6443	-30.40	3.8188	-149.60
.504	.5543	-.3234	.6417	-30.27	3.8532	-149.73
.502	.5528	-.3209	.6392	-30.13	3.8877	-149.87

TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
.500	.5513	-.3183	.6366	-30.00	3.9224	-150.00
.498	.5499	-.3158	.6341	-29.87	3.9572	-150.13
.496	.5484	-.3132	.6315	-29.74	3.9922	-150.26
.494	.5469	-.3107	.6290	-29.60	4.0273	-150.40
.492	.5454	-.3082	.6264	-29.47	4.0625	-150.53
.490	.5439	-.3057	.6239	-29.34	4.0979	-150.66
.488	.5423	-.3032	.6213	-29.21	4.1334	-150.79
.486	.5408	-.3007	.6188	-29.08	4.1691	-150.92
.484	.5393	-.2983	.6162	-28.95	4.2049	-151.05
.482	.5377	-.2958	.6137	-28.82	4.2408	-151.18
.480	.5361	-.2934	.6112	-28.69	4.2770	-151.31
.478	.5346	-.2909	.6086	-28.55	4.3132	-151.45
.476	.5330	-.2885	.6061	-28.42	4.3497	-151.58
.474	.5314	-.2861	.6035	-28.29	4.3862	-151.71
.472	.5298	-.2837	.6010	-28.16	4.4230	-151.84
.470	.5282	-.2813	.5984	-28.03	4.4598	-151.97
.468	.5266	-.2789	.5959	-27.90	4.4969	-152.10
.466	.5250	-.2765	.5933	-27.77	4.5341	-152.23
.464	.5233	-.2741	.5908	-27.65	4.5714	-152.35
.462	.5217	-.2718	.5882	-27.52	4.6090	-152.48
.460	.5200	-.2694	.5857	-27.39	4.6466	-152.61
.458	.5184	-.2671	.5831	-27.26	4.6845	-152.74
.456	.5167	-.2648	.5806	-27.13	4.7225	-152.87
.454	.5150	-.2624	.5781	-27.00	4.7607	-153.00
.452	.5134	-.2601	.5755	-26.87	4.7990	-153.13
.450	.5117	-.2578	.5730	-26.74	4.8375	-153.26
.448	.5100	-.2555	.5704	-26.62	4.8762	-153.38
.446	.5083	-.2533	.5679	-26.49	4.9151	-153.51
.444	.5065	-.2510	.5653	-26.36	4.9541	-153.64
.442	.5048	-.2487	.5628	-26.23	4.9933	-153.77
.440	.5031	-.2465	.5602	-26.10	5.0327	-153.90
.438	.5013	-.2443	.5577	-25.98	5.0723	-154.02
.436	.4996	-.2420	.5551	-25.85	5.1121	-154.15
.434	.4978	-.2398	.5526	-25.72	5.1520	-154.28
.432	.4961	-.2376	.5500	-25.59	5.1921	-154.41
.430	.4943	-.2354	.5475	-25.47	5.2324	-154.53
.428	.4925	-.2332	.5449	-25.34	5.2729	-154.66
.426	.4907	-.2311	.5424	-25.21	5.3136	-154.79
.424	.4889	-.2289	.5399	-25.09	5.3545	-154.91
.422	.4871	-.2267	.5373	-24.96	5.3955	-155.04
.420	.4853	-.2246	.5348	-24.83	5.4368	-155.17
.418	.4835	-.2225	.5322	-24.71	5.4783	-155.29
.416	.4817	-.2203	.5297	-24.58	5.5199	-155.42
.414	.4798	-.2182	.5271	-24.46	5.5618	-155.54
.412	.4780	-.2161	.5246	-24.33	5.6038	-155.67
.410	.4761	-.2140	.5220	-24.20	5.6461	-155.80
.408	.4743	-.2119	.5195	-24.08	5.6886	-155.92
.406	.4724	-.2099	.5169	-23.95	5.7313	-156.05
.404	.4705	-.2078	.5144	-23.83	5.7742	-156.17
.402	.4687	-.2058	.5118	-23.70	5.8173	-156.30

TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
.400	.4668	-.2037	.5093	-23.58	5.8606	-156.42
.398	.4649	-.2017	.5067	-23.45	5.9041	-156.55
.396	.4630	-.1997	.5042	-23.33	5.9479	-156.67
.394	.4611	-.1977	.5017	-23.20	5.9919	-156.80
.392	.4592	-.1957	.4991	-23.08	6.0361	-156.92
.390	.4572	-.1937	.4966	-22.95	6.0805	-157.05
.388	.4553	-.1917	.4940	-22.83	6.1252	-157.17
.386	.4534	-.1897	.4915	-22.71	6.1700	-157.29
.384	.4514	-.1877	.4889	-22.58	6.2152	-157.42
.382	.4495	-.1858	.4864	-22.46	6.2605	-157.54
.380	.4475	-.1839	.4838	-22.33	6.3061	-157.67
.378	.4456	-.1819	.4813	-22.21	6.3520	-157.79
.376	.4436	-.1800	.4787	-22.09	6.3980	-157.91
.374	.4416	-.1781	.4762	-21.96	6.4444	-158.04
.372	.4397	-.1762	.4736	-21.84	6.4909	-158.16
.370	.4377	-.1743	.4711	-21.72	6.5378	-158.28
.368	.4357	-.1724	.4686	-21.59	6.5848	-158.41
.366	.4337	-.1706	.4660	-21.47	6.6322	-158.53
.364	.4317	-.1687	.4635	-21.35	6.6798	-158.65
.362	.4297	-.1669	.4609	-21.22	6.7276	-158.78
.360	.4276	-.1650	.4584	-21.10	6.7757	-158.90
.358	.4256	-.1632	.4558	-20.98	6.8241	-159.02
.356	.4236	-.1614	.4533	-20.85	6.8728	-159.15
.354	.4215	-.1596	.4507	-20.73	6.9217	-159.27
.352	.4195	-.1578	.4482	-20.61	6.9709	-159.39
.350	.4174	-.1560	.4456	-20.49	7.0204	-159.51
.348	.4154	-.1542	.4431	-20.37	7.0702	-159.63
.346	.4133	-.1524	.4405	-20.24	7.1203	-159.76
.344	.4113	-.1507	.4380	-20.12	7.1706	-159.88
.342	.4092	-.1489	.4354	-20.00	7.2213	-160.00
.340	.4071	-.1472	.4329	-19.88	7.2722	-160.12
.338	.4050	-.1455	.4304	-19.76	7.3235	-160.24
.336	.4029	-.1437	.4278	-19.63	7.3750	-160.37
.334	.4008	-.1420	.4253	-19.51	7.4269	-160.49
.332	.3987	-.1403	.4227	-19.39	7.4790	-160.61
.330	.3966	-.1387	.4202	-19.27	7.5315	-160.73
.328	.3945	-.1370	.4176	-19.15	7.5843	-160.85
.326	.3924	-.1353	.4151	-19.03	7.6374	-160.97
.324	.3903	-.1337	.4125	-18.91	7.6909	-161.09
.322	.3881	-.1320	.4100	-18.78	7.7447	-161.22
.320	.3860	-.1304	.4074	-18.66	7.7988	-161.34
.318	.3839	-.1288	.4049	-18.54	7.8532	-161.46
.316	.3817	-.1271	.4023	-18.42	7.9080	-161.58
.314	.3796	-.1255	.3998	-18.30	7.9632	-161.70
.312	.3774	-.1239	.3973	-18.18	8.0187	-161.82
.310	.3753	-.1224	.3947	-18.06	8.0746	-161.94
.308	.3731	-.1208	.3922	-17.94	8.1308	-162.06
.306	.3709	-.1192	.3896	-17.82	8.1874	-162.18
.304	.3687	-.1177	.3871	-17.70	8.2443	-162.30
.302	.3666	-.1161	.3845	-17.58	8.3017	-162.42

TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
.300	.3644	-.1146	.3820	-17.46	8.3594	-162.54
.298	.3622	-.1131	.3794	-17.34	8.4175	-162.66
.296	.3600	-.1116	.3769	-17.22	8.4760	-162.78
.294	.3578	-.1101	.3743	-17.10	8.5348	-162.90
.292	.3556	-.1086	.3718	-16.98	8.5941	-163.02
.290	.3534	-.1071	.3692	-16.86	8.6538	-163.14
.288	.3512	-.1056	.3667	-16.74	8.7139	-163.26
.286	.3489	-.1041	.3641	-16.62	8.7745	-163.38
.284	.3467	-.1027	.3616	-16.50	8.8354	-163.50
.282	.3445	-.1013	.3591	-16.38	8.8968	-163.62
.280	.3422	-.0998	.3565	-16.26	8.9586	-163.74
.278	.3400	-.0984	.3540	-16.14	9.0209	-163.86
.276	.3378	-.0970	.3514	-16.02	9.0836	-163.98
.274	.3355	-.0956	.3489	-15.90	9.1468	-164.10
.272	.3333	-.0942	.3463	-15.78	9.2104	-164.22
.270	.3310	-.0928	.3438	-15.66	9.2745	-164.34
.268	.3287	-.0914	.3412	-15.55	9.3391	-164.45
.266	.3265	-.0901	.3387	-15.43	9.4042	-164.57
.264	.3242	-.0887	.3361	-15.31	9.4697	-164.69
.262	.3219	-.0874	.3336	-15.19	9.5358	-164.81
.260	.3197	-.0861	.3310	-15.07	9.6023	-164.93
.258	.3174	-.0848	.3285	-14.95	9.6694	-165.05
.256	.3151	-.0834	.3259	-14.83	9.7370	-165.17
.254	.3128	-.0821	.3234	-14.71	9.8051	-165.29
.252	.3105	-.0809	.3209	-14.60	9.8738	-165.40
.250	.3082	-.0796	.3183	-14.48	9.9430	-165.52
.248	.3059	-.0783	.3158	-14.36	10.0128	-165.64
.246	.3036	-.0771	.3132	-14.24	10.0831	-165.76
.244	.3013	-.0758	.3107	-14.12	10.1540	-165.88
.242	.2990	-.0746	.3081	-14.00	10.2255	-166.00
.240	.2966	-.0733	.3056	-13.89	10.2976	-166.11
.238	.2943	-.0721	.3030	-13.77	10.3703	-166.23
.236	.2920	-.0709	.3005	-13.65	10.4436	-166.35
.234	.2897	-.0697	.2979	-13.53	10.5175	-166.47
.232	.2873	-.0685	.2954	-13.41	10.5920	-166.59
.230	.2850	-.0674	.2928	-13.30	10.6672	-166.70
.228	.2827	-.0662	.2903	-13.18	10.7431	-166.82
.226	.2803	-.0650	.2878	-13.06	10.8196	-166.94
.224	.2780	-.0639	.2852	-12.94	10.8968	-167.06
.222	.2756	-.0628	.2827	-12.83	10.9747	-167.17
.220	.2733	-.0616	.2801	-12.71	11.0533	-167.29
.218	.2709	-.0605	.2776	-12.59	11.1327	-167.41
.216	.2685	-.0594	.2750	-12.47	11.2127	-167.53
.214	.2662	-.0583	.2725	-12.36	11.2935	-167.64
.212	.2638	-.0572	.2699	-12.24	11.3751	-167.76
.210	.2614	-.0561	.2674	-12.12	11.4574	-167.88
.208	.2590	-.0551	.2648	-12.01	11.5405	-167.99
.206	.2567	-.0540	.2623	-11.89	11.6244	-168.11
.204	.2543	-.0530	.2597	-11.77	11.7092	-168.23
.202	.2519	-.0520	.2572	-11.65	11.7948	-168.35

TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
.200	.2495	-.0509	.2546	-11.54	11.8812	-168.46
.198	.2471	-.0499	.2521	-11.42	11.9685	-168.58
.196	.2447	-.0489	.2496	-11.30	12.0567	-168.70
.194	.2423	-.0479	.2470	-11.19	12.1458	-168.81
.192	.2399	-.0469	.2445	-11.07	12.2358	-168.93
.190	.2375	-.0460	.2419	-10.95	12.3267	-169.05
.188	.2351	-.0450	.2394	-10.84	12.4186	-169.16
.186	.2327	-.0440	.2368	-10.72	12.5115	-169.28
.184	.2303	-.0431	.2343	-10.60	12.6054	-169.40
.182	.2279	-.0422	.2317	-10.49	12.7004	-169.51
.180	.2254	-.0413	.2292	-10.37	12.7963	-169.63
.178	.2230	-.0403	.2266	-10.25	12.8934	-169.75
.176	.2206	-.0394	.2241	-10.14	12.9915	-169.86
.174	.2182	-.0385	.2215	-10.02	13.0908	-169.98
.172	.2157	-.0377	.2190	-9.90	13.1912	-170.10
.170	.2133	-.0368	.2165	-9.79	13.2928	-170.21
.168	.2109	-.0359	.2139	-9.67	13.3956	-170.33
.166	.2084	-.0351	.2114	-9.56	13.4996	-170.44
.164	.2060	-.0342	.2088	-9.44	13.6049	-170.56
.162	.2035	-.0334	.2063	-9.32	13.7115	-170.68
.160	.2011	-.0326	.2037	-9.21	13.8194	-170.79
.158	.1986	-.0318	.2012	-9.09	13.9286	-170.91
.156	.1962	-.0310	.1986	-8.97	14.0393	-171.03
.154	.1937	-.0302	.1961	-8.86	14.1514	-171.14
.152	.1913	-.0294	.1935	-8.74	14.2649	-171.26
.150	.1888	-.0286	.1910	-8.63	14.3800	-171.37
.148	.1864	-.0279	.1884	-8.51	14.4966	-171.49
.146	.1839	-.0271	.1859	-8.40	14.6147	-171.60
.144	.1814	-.0264	.1833	-8.28	14.7345	-171.72
.142	.1790	-.0257	.1808	-8.16	14.8560	-171.84
.140	.1765	-.0250	.1783	-8.05	14.9792	-171.95
.138	.1740	-.0242	.1757	-7.93	15.1042	-172.07
.136	.1716	-.0235	.1732	-7.82	15.2310	-172.18
.134	.1691	-.0229	.1706	-7.70	15.3597	-172.30
.132	.1666	-.0222	.1681	-7.59	15.4903	-172.41
.130	.1641	-.0215	.1655	-7.47	15.6229	-172.53
.128	.1616	-.0209	.1630	-7.35	15.7576	-172.65
.126	.1591	-.0202	.1604	-7.24	15.8944	-172.76
.124	.1567	-.0196	.1579	-7.12	16.0334	-172.88
.122	.1542	-.0190	.1553	-7.01	16.1746	-172.99
.120	.1517	-.0183	.1528	-6.89	16.3182	-173.11
.118	.1492	-.0177	.1502	-6.78	16.4642	-173.22
.116	.1467	-.0171	.1477	-6.66	16.6126	-173.34
.114	.1442	-.0165	.1451	-6.55	16.7637	-173.45
.112	.1417	-.0160	.1426	-6.43	16.9174	-173.57
.110	.1392	-.0154	.1401	-6.32	17.0739	-173.68
.108	.1367	-.0149	.1375	-6.20	17.2333	-173.80
.106	.1342	-.0143	.1350	-6.08	17.3957	-173.92
.104	.1317	-.0138	.1324	-5.97	17.5611	-174.03
.102	.1292	-.0132	.1299	-5.85	17.7298	-174.15

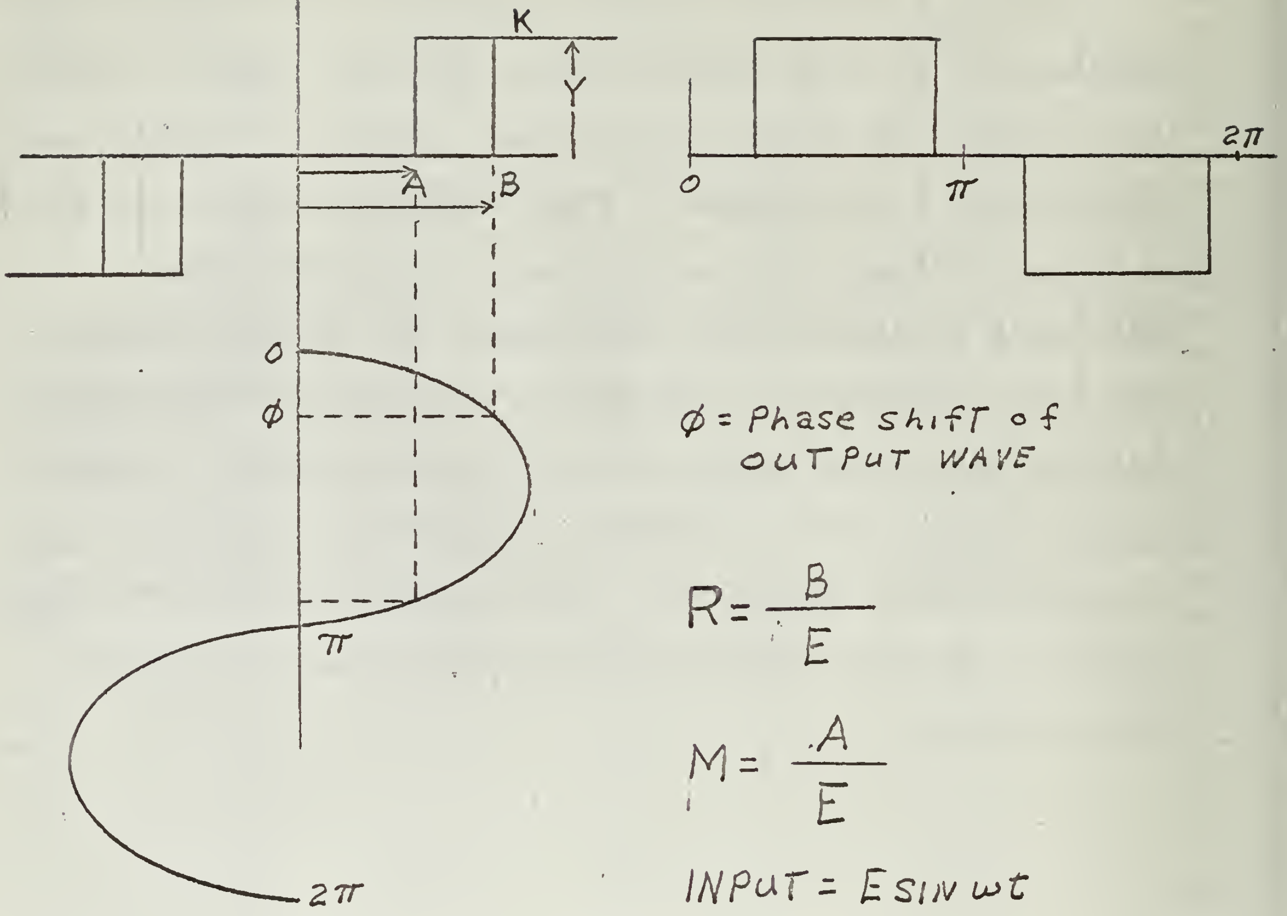
TWO POSITION RELAY

R	REAL	IMAG	GD(JW)	PHASE	DB	THETA
.100	.1267	-.0127	.1273	-5.74	17.9018	-174.26
.098	.1242	-.0122	.1248	-5.62	18.0773	-174.38
.096	.1217	-.0117	.1222	-5.51	18.2564	-174.49
.094	.1192	-.0113	.1197	-5.39	18.4392	-174.61
.092	.1166	-.0108	.1171	-5.28	18.6260	-174.72
.090	.1141	-.0103	.1146	-5.16	18.8169	-174.84
.088	.1116	-.0099	.1120	-5.05	19.0121	-174.95
.086	.1091	-.0094	.1095	-4.93	19.2118	-175.07
.084	.1066	-.0090	.1070	-4.82	19.4162	-175.18
.082	.1041	-.0086	.1044	-4.70	19.6255	-175.30
.080	.1015	-.0081	.1019	-4.59	19.8400	-175.41
.078	.0990	-.0077	.0993	-4.47	20.0599	-175.53
.076	.0965	-.0074	.0968	-4.36	20.2855	-175.64
.074	.0940	-.0070	.0942	-4.24	20.5172	-175.76
.072	.0914	-.0066	.0917	-4.13	20.7551	-175.87
.070	.0889	-.0062	.0891	-4.01	20.9998	-175.99
.068	.0864	-.0059	.0866	-3.90	21.2516	-176.10
.066	.0839	-.0055	.0840	-3.78	21.5109	-176.22
.064	.0813	-.0052	.0815	-3.67	21.7782	-176.33
.062	.0788	-.0049	.0789	-3.55	22.0540	-176.45
.060	.0763	-.0046	.0764	-3.44	22.3388	-176.56
.058	.0737	-.0043	.0738	-3.33	22.6332	-176.67
.056	.0712	-.0040	.0713	-3.21	22.9380	-176.79
.054	.0687	-.0037	.0688	-3.10	23.2539	-176.90
.052	.0661	-.0034	.0662	-2.98	23.5817	-177.02
.050	.0636	-.0032	.0637	-2.87	23.9224	-177.13
.048	.0610	-.0029	.0611	-2.75	24.2770	-177.25
.046	.0585	-.0027	.0586	-2.64	24.6466	-177.36
.044	.0560	-.0025	.0560	-2.52	25.0327	-177.48
.042	.0534	-.0022	.0535	-2.41	25.4368	-177.59
.040	.0509	-.0020	.0509	-2.29	25.8606	-177.71
.038	.0483	-.0018	.0484	-2.18	26.3061	-177.82
.036	.0458	-.0017	.0458	-2.06	26.7757	-177.94
.034	.0433	-.0015	.0433	-1.95	27.2722	-178.05
.032	.0407	-.0013	.0407	-1.83	27.7988	-178.17
.030	.0382	-.0011	.0382	-1.72	28.3594	-178.28
.028	.0356	-.0010	.0357	-1.60	28.9586	-178.40
.026	.0331	-.0009	.0331	-1.49	29.6023	-178.51
.024	.0305	-.0007	.0306	-1.38	30.2976	-178.62
.022	.0280	-.0006	.0280	-1.26	31.0533	-178.74
.020	.0255	-.0005	.0255	-1.15	31.8812	-178.85
.018	.0229	-.0004	.0229	-1.03	32.7963	-178.97
.016	.0204	-.0003	.0204	-.92	33.8194	-179.08
.014	.0178	-.0002	.0178	-.80	34.9792	-179.20
.012	.0153	-.0002	.0153	-.69	36.3182	-179.31
.010	.0127	-.0001	.0127	-.57	37.9018	-179.43
.008	.0102	-.0001	.0102	-.46	39.8400	-179.54
.006	.0076	-.0000	.0076	-.34	42.3388	-179.66
.004	.0051	-.0000	.0051	-.23	45.8606	-179.77
.002	.0025	-.0000	.0025	-.11	51.8812	-179.89

APPENDIX V

Relay With Hysteresis And Dead Zone

Similar to the two position relay with hysteresis, this nonlinearity is also rather common, and also tends to stabilize a system with small oscillations. It has the additional characteristic of deadzone. Thus, for small signal variations no output voltage would be realized. In addition the hysteresis provides some stabilization for command signals with small variations. For example, assume an input signal which is just large enough to activate the relay. If this signal then has small variations chattering could result in a system without hysteresis. The hysteresis allows the input signal to decrease by some fixed value before the output drops to zero.



ϕ = Phase shift of OUTPUT WAVE

$$R = \frac{B}{E}$$

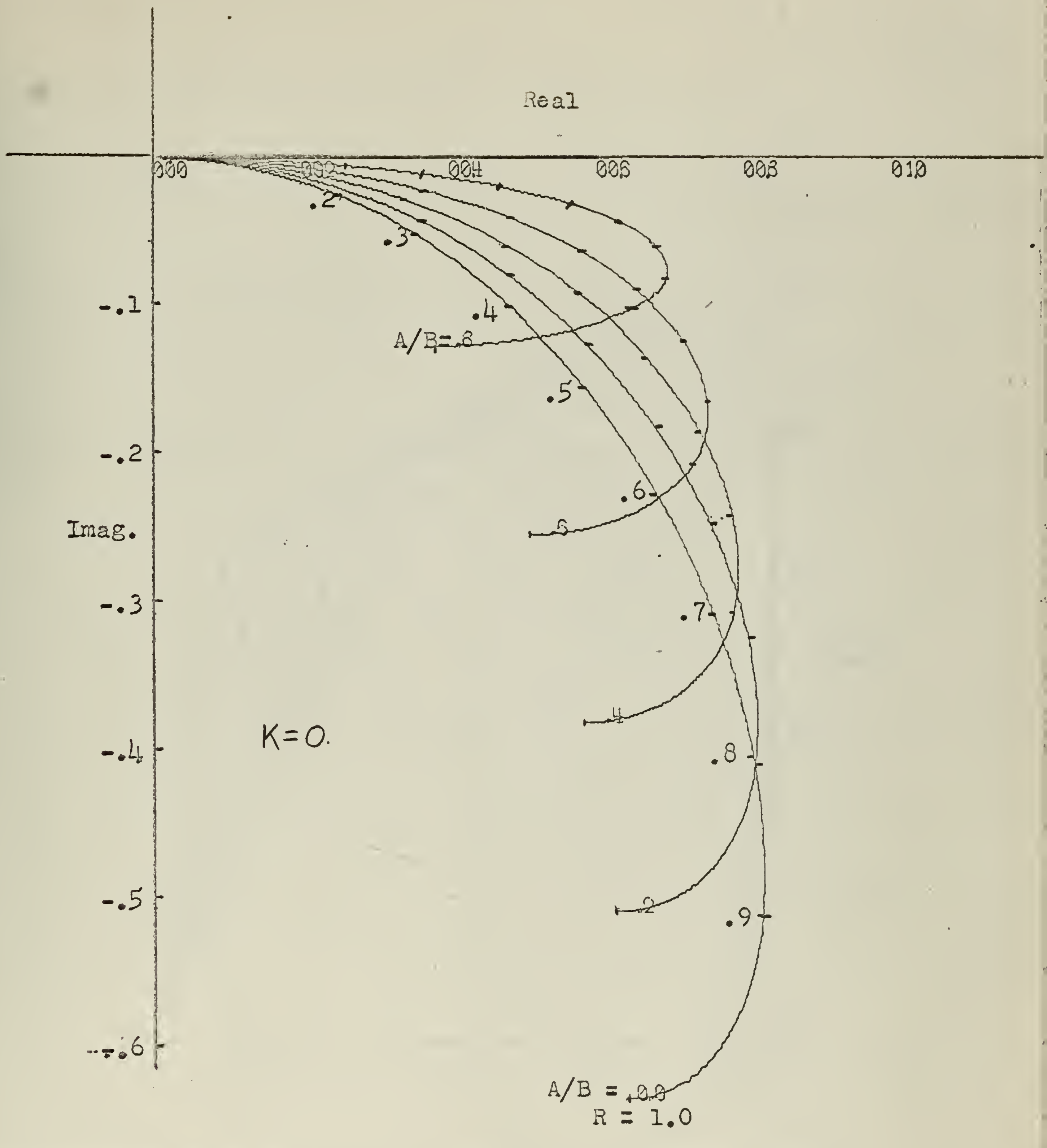
$$M = \frac{A}{E}$$

$$\text{INPUT} = E \sin \omega t$$

$$G_D(j\omega) = \frac{2Y}{\pi E}\sqrt{2(1-RM)+2\sqrt{(1-R^2)(1-M^2)}}$$

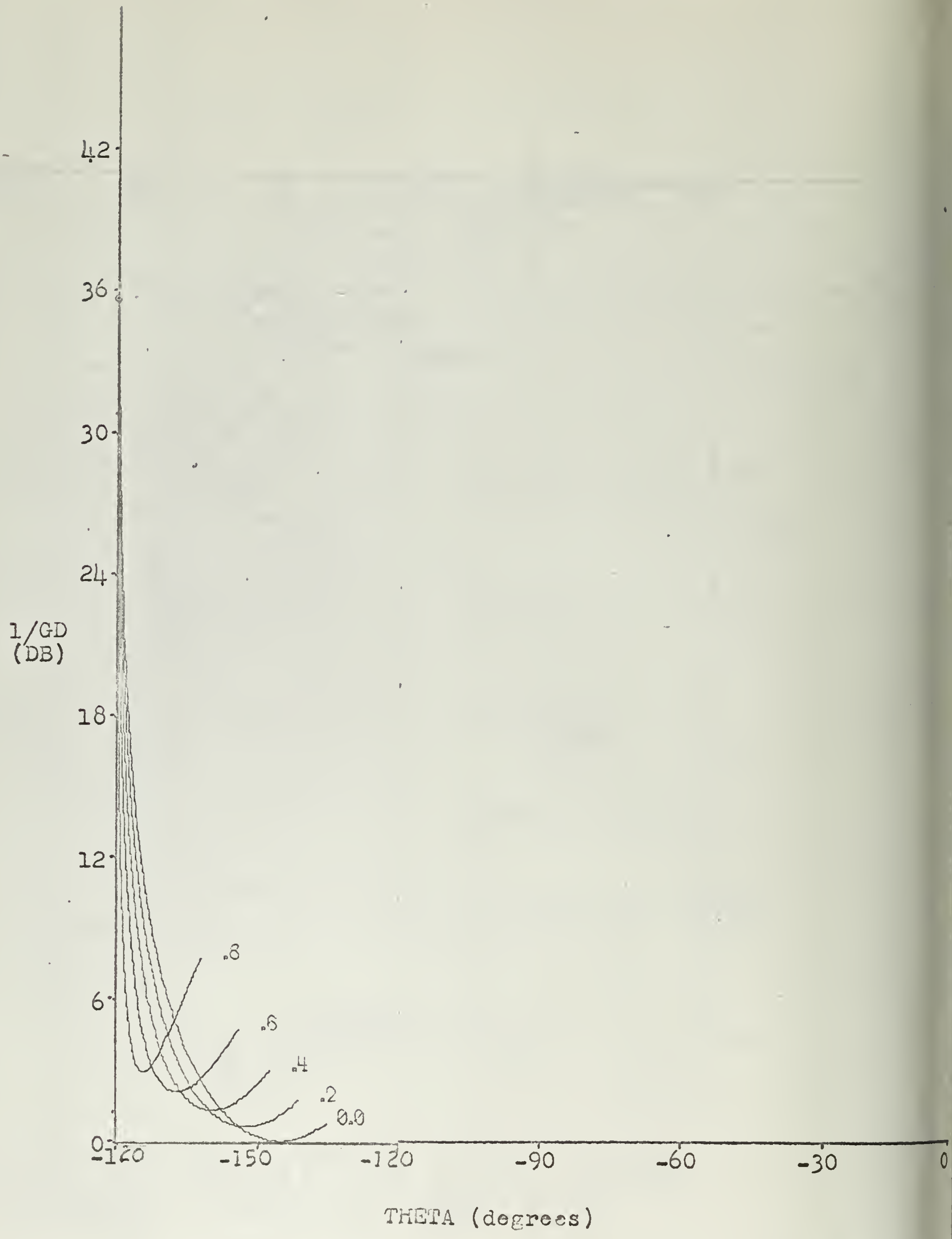
$$\angle\, \mathrm{Tan}^{-1} \frac{M-R}{\sqrt{1-M^2}+\sqrt{1-R^2}}$$

Figure V-1
Relay With Hysteresis and Deadzone



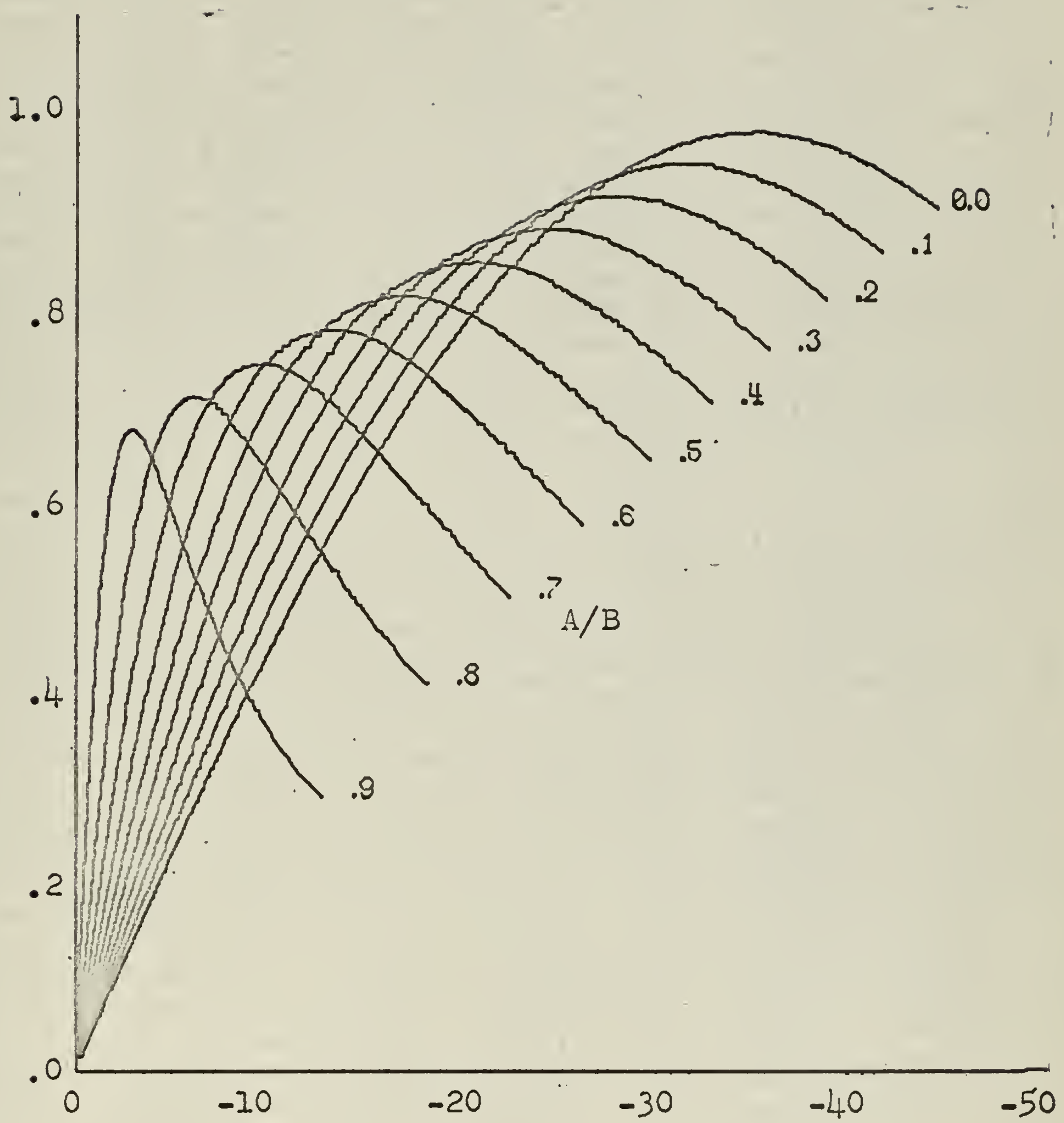
RELAY WITH HYSTERESIS AND DEAD ZONE
REAL AND IMAGINARY COMPONENTS

Figure V-2



RELAY WITH HYSTERESIS AND DEAD ZONE
MAGNITUDE (DB) VS PHASE

Figure V-3



RELAY WITH HYSTERESIS AND DEAD ZONE

MAGNITUDE AND PHASE

Figure V-4

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .0

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
1.000	.6366	-.6366	.9003	-45.00	.9121	-135.00
.995	.6967	-.6303	.9395	-42.13	.5422	-137.87
.990	.7192	-.6240	.9521	-40.95	.4263	-139.05
.985	.7353	-.6177	.9603	-40.03	.3520	-139.97
.980	.7480	-.6114	.9661	-39.26	.2994	-140.74
.975	.7586	-.6052	.9704	-38.58	.2606	-141.42
.970	.7676	-.5990	.9737	-37.97	.2316	-142.03
.965	.7754	-.5928	.9761	-37.40	.2101	-142.60
.960	.7823	-.5867	.9778	-36.87	.1946	-143.13
.955	.7883	-.5806	.9790	-36.37	.1839	-143.63
.950	.7936	-.5746	.9798	-35.90	.1775	-144.10
.945	.7984	-.5685	.9801	-35.45	.1745	-144.55
.940	.8026	-.5625	.9801	-35.03	.1747	-144.97
.935	.8063	-.5566	.9798	-34.61	.1776	-145.39
.930	.8097	-.5506	.9792	-34.22	.1830	-145.78
.925	.8126	-.5447	.9783	-33.83	.1906	-146.17
.920	.8152	-.5388	.9772	-33.46	.2002	-146.54
.915	.8175	-.5330	.9759	-33.10	.2117	-146.90
.910	.8195	-.5272	.9744	-32.75	.2249	-147.25
.905	.8212	-.5214	.9728	-32.41	.2397	-147.59
.900	.8227	-.5157	.9710	-32.08	.2560	-147.92
.895	.8239	-.5100	.9690	-31.75	.2738	-148.25
.890	.8249	-.5043	.9669	-31.44	.2928	-148.56
.885	.8257	-.4986	.9646	-31.13	.3131	-148.87
.880	.8263	-.4930	.9622	-30.82	.3346	-149.18
.875	.8267	-.4874	.9597	-30.52	.3572	-149.48
.870	.8269	-.4819	.9571	-30.23	.3810	-149.77
.865	.8270	-.4763	.9544	-29.94	.4057	-150.06
.860	.8269	-.4708	.9515	-29.66	.4315	-150.34
.855	.8266	-.4654	.9486	-29.38	.4583	-150.62
.850	.8262	-.4600	.9456	-29.11	.4859	-150.89
.845	.8256	-.4546	.9425	-28.84	.5145	-151.16
.840	.8249	-.4492	.9393	-28.57	.5440	-151.43
.835	.8241	-.4439	.9360	-28.31	.5744	-151.69
.830	.8231	-.4386	.9327	-28.05	.6055	-151.95
.825	.8220	-.4333	.9292	-27.79	.6375	-152.21
.820	.8208	-.4281	.9257	-27.54	.6703	-152.46
.815	.8195	-.4229	.9222	-27.29	.7039	-152.71
.810	.8181	-.4177	.9185	-27.05	.7382	-152.95
.805	.8165	-.4125	.9148	-26.81	.7733	-153.19
.800	.8149	-.4074	.9111	-26.57	.8091	-153.43
.795	.8131	-.4024	.9072	-26.33	.8457	-153.67
.790	.8113	-.3973	.9033	-26.09	.8829	-153.91
.785	.8093	-.3923	.8994	-25.86	.9209	-154.14
.780	.8073	-.3873	.8954	-25.63	.9596	-154.37
.775	.8052	-.3824	.8914	-25.40	.9990	-154.60
.770	.8030	-.3775	.8873	-25.18	1.0390	-154.82
.765	.8007	-.3726	.8831	-24.95	1.0798	-155.05
.760	.7983	-.3677	.8789	-24.73	1.1212	-155.27
.755	.7958	-.3629	.8747	-24.51	1.1633	-155.49

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .0

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.750	.7933	-.3581	.8704	-24.30	1.2060	-155.70
.745	.7907	-.3533	.8660	-24.08	1.2495	-155.92
.740	.7880	-.3486	.8616	-23.87	1.2935	-156.13
.735	.7852	-.3439	.8572	-23.65	1.3383	-156.35
.730	.7824	-.3393	.8527	-23.44	1.3837	-156.56
.725	.7794	-.3346	.8482	-23.23	1.4297	-156.77
.720	.7765	-.3300	.8437	-23.03	1.4764	-156.97
.715	.7734	-.3255	.8391	-22.82	1.5237	-157.18
.710	.7703	-.3209	.8345	-22.62	1.5717	-157.38
.705	.7671	-.3164	.8298	-22.41	1.6204	-157.59
.700	.7639	-.3119	.8251	-22.21	1.6697	-157.79
.695	.7606	-.3075	.8204	-22.01	1.7196	-157.99
.690	.7572	-.3031	.8156	-21.82	1.7702	-158.18
.685	.7538	-.2987	.8108	-21.62	1.8215	-158.38
.680	.7503	-.2944	.8060	-21.42	1.8734	-158.58
.675	.7468	-.2901	.8011	-21.23	1.9260	-158.77
.670	.7432	-.2858	.7962	-21.03	1.9792	-158.97
.665	.7395	-.2815	.7913	-20.84	2.0331	-159.16
.660	.7358	-.2773	.7863	-20.65	2.0877	-159.35
.655	.7321	-.2731	.7814	-20.46	2.1430	-159.54
.650	.7283	-.2690	.7763	-20.27	2.1989	-159.73
.645	.7244	-.2649	.7713	-20.08	2.2555	-159.92
.640	.7205	-.2608	.7662	-19.90	2.3128	-160.10
.635	.7165	-.2567	.7611	-19.71	2.3707	-160.29
.630	.7125	-.2527	.7560	-19.53	2.4294	-160.47
.625	.7085	-.2487	.7509	-19.34	2.4888	-160.66
.620	.7044	-.2447	.7457	-19.16	2.5489	-160.84
.615	.7002	-.2408	.7405	-18.98	2.6096	-161.02
.610	.6961	-.2369	.7353	-18.79	2.6712	-161.21
.605	.6918	-.2330	.7300	-18.61	2.7334	-161.39
.600	.6875	-.2292	.7247	-18.44	2.7964	-161.56
.595	.6832	-.2254	.7194	-18.26	2.8601	-161.74
.590	.6789	-.2216	.7141	-18.08	2.9245	-161.92
.585	.6745	-.2179	.7088	-17.90	2.9897	-162.10
.580	.6700	-.2142	.7034	-17.73	3.0557	-162.27
.575	.6655	-.2105	.6980	-17.55	3.1224	-162.45
.570	.6610	-.2068	.6926	-17.38	3.1900	-162.62
.565	.6565	-.2032	.6872	-17.20	3.2583	-162.80
.560	.6519	-.1996	.6818	-17.03	3.3274	-162.97
.555	.6472	-.1961	.6763	-16.86	3.3973	-163.14
.550	.6426	-.1926	.6708	-16.68	3.4681	-163.32
.545	.6379	-.1891	.6653	-16.51	3.5397	-163.49
.540	.6331	-.1856	.6598	-16.34	3.6121	-163.66
.535	.6283	-.1822	.6542	-16.17	3.6854	-163.83
.530	.6235	-.1788	.6487	-16.00	3.7596	-164.00
.525	.6187	-.1755	.6431	-15.83	3.8346	-164.17
.520	.6138	-.1721	.6375	-15.67	3.9106	-164.33
.515	.6089	-.1688	.6319	-15.50	3.9874	-164.50
.510	.6040	-.1656	.6262	-15.33	4.0652	-164.67
.505	.5990	-.1624	.6206	-15.17	4.1459	-164.83

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .0

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.500	.5940	-.1592	.6149	-15.00	4.2235	-165.00
.495	.5889	-.1560	.6092	-14.84	4.3042	-165.16
.490	.5839	-.1529	.6035	-14.67	4.3858	-165.33
.485	.5788	-.1498	.5978	-14.51	4.4684	-165.49
.480	.5736	-.1467	.5921	-14.34	4.5520	-165.66
.475	.5685	-.1436	.5864	-14.18	4.6367	-165.82
.470	.5633	-.1406	.5806	-14.02	4.7224	-165.98
.465	.5581	-.1377	.5748	-13.86	4.8092	-166.14
.460	.5529	-.1347	.5690	-13.69	4.8971	-166.31
.455	.5476	-.1318	.5632	-13.53	4.9861	-166.47
.450	.5423	-.1289	.5574	-13.37	5.0763	-166.63
.445	.5370	-.1261	.5516	-13.21	5.1676	-166.79
.440	.5317	-.1233	.5458	-13.05	5.2601	-166.95
.435	.5263	-.1205	.5399	-12.89	5.3538	-167.11
.430	.5209	-.1177	.5340	-12.73	5.4487	-167.27
.425	.5155	-.1150	.5281	-12.58	5.5449	-167.42
.420	.5100	-.1123	.5223	-12.42	5.6424	-167.58
.415	.5046	-.1096	.5163	-12.26	5.7412	-167.74
.410	.4991	-.1070	.5104	-12.10	5.8414	-167.90
.405	.4936	-.1044	.5045	-11.95	5.9429	-168.05
.400	.4880	-.1019	.4986	-11.79	6.0458	-168.21
.395	.4825	-.0993	.4926	-11.63	6.1501	-168.37
.390	.4769	-.0968	.4866	-11.48	6.2560	-168.52
.385	.4713	-.0944	.4807	-11.32	6.3633	-168.68
.380	.4657	-.0919	.4747	-11.17	6.4722	-168.83
.375	.4600	-.0895	.4687	-11.01	6.5826	-168.99
.370	.4544	-.0872	.4627	-10.86	6.6947	-169.14
.365	.4487	-.0848	.4566	-10.70	6.8084	-169.30
.360	.4430	-.0825	.4506	-10.55	6.9239	-169.45
.355	.4373	-.0802	.4446	-10.40	7.0410	-169.60
.350	.4315	-.0780	.4385	-10.24	7.1600	-169.76
.345	.4258	-.0758	.4325	-10.09	7.2808	-169.91
.340	.4200	-.0736	.4264	-9.94	7.4036	-170.06
.335	.4142	-.0714	.4203	-9.79	7.5282	-170.21
.330	.4084	-.0693	.4142	-9.63	7.6549	-170.37
.325	.4026	-.0672	.4081	-9.48	7.7837	-170.52
.320	.3967	-.0652	.4020	-9.33	7.9145	-170.67
.315	.3909	-.0632	.3959	-9.18	8.0476	-170.82
.310	.3850	-.0612	.3898	-9.03	8.1829	-170.97
.305	.3791	-.0592	.3837	-8.88	8.3205	-171.12
.300	.3732	-.0573	.3775	-8.73	8.4606	-171.27
.295	.3672	-.0554	.3714	-8.58	8.6031	-171.42
.290	.3613	-.0535	.3653	-8.43	8.7482	-171.57
.285	.3553	-.0517	.3591	-8.28	8.8959	-171.72
.280	.3494	-.0499	.3529	-8.13	9.0464	-171.87
.275	.3434	-.0481	.3467	-7.98	9.1997	-172.02
.270	.3374	-.0464	.3406	-7.83	9.3559	-172.17
.265	.3314	-.0447	.3344	-7.68	9.5152	-172.32
.260	.3253	-.0430	.3282	-7.54	9.6777	-172.46
.255	.3193	-.0414	.3220	-7.39	9.8434	-172.61

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .0

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.250	.3133	-.0398	.3158	-7.24	10.0125	-172.76
.245	.3072	-.0382	.3096	-7.09	10.1852	-172.91
.240	.3011	-.0367	.3033	-6.94	10.3615	-173.06
.235	.2950	-.0352	.2971	-6.80	10.5417	-173.20
.230	.2889	-.0337	.2909	-6.65	10.7259	-173.35
.225	.2828	-.0322	.2846	-6.50	10.9142	-173.50
.220	.2767	-.0308	.2784	-6.35	11.1069	-173.65
.215	.2705	-.0294	.2721	-6.21	11.3041	-173.79
.210	.2644	-.0281	.2659	-6.06	11.5061	-173.94
.205	.2582	-.0268	.2596	-5.91	11.7131	-174.09
.200	.2521	-.0255	.2534	-5.77	11.9253	-174.23
.195	.2459	-.0242	.2471	-5.62	12.1430	-174.38
.190	.2397	-.0230	.2408	-5.48	12.3665	-174.52
.185	.2335	-.0218	.2345	-5.33	12.5960	-174.67
.180	.2273	-.0206	.2282	-5.19	12.8320	-174.81
.175	.2211	-.0195	.2220	-5.04	13.0747	-174.96
.170	.2149	-.0184	.2157	-4.89	13.3246	-175.11
.165	.2086	-.0173	.2094	-4.75	13.5820	-175.25
.160	.2024	-.0163	.2031	-4.60	13.8475	-175.40
.155	.1962	-.0153	.1968	-4.46	14.1215	-175.54
.150	.1899	-.0143	.1904	-4.31	14.4046	-175.69
.145	.1836	-.0134	.1841	-4.17	14.6975	-175.83
.140	.1774	-.0125	.1778	-4.02	15.0007	-175.98
.135	.1711	-.0116	.1715	-3.88	15.3151	-176.12
.130	.1648	-.0108	.1652	-3.73	15.6414	-176.27
.125	.1585	-.0099	.1588	-3.59	15.9807	-176.41
.120	.1522	-.0092	.1525	-3.45	16.3339	-176.55
.115	.1459	-.0084	.1462	-3.30	16.7023	-176.70
.110	.1396	-.0077	.1398	-3.16	17.0872	-176.84
.105	.1333	-.0070	.1335	-3.01	17.4901	-176.99
.100	.1270	-.0064	.1272	-2.87	17.9127	-177.13
.095	.1207	-.0057	.1208	-2.73	18.3572	-177.27
.090	.1144	-.0052	.1145	-2.58	18.8258	-177.42
.085	.1080	-.0046	.1081	-2.44	19.3213	-177.56
.080	.1017	-.0041	.1018	-2.29	19.8470	-177.71
.075	.0954	-.0036	.0954	-2.15	20.4067	-177.85
.070	.0890	-.0031	.0891	-2.01	21.0052	-177.99
.065	.0827	-.0027	.0827	-1.86	21.6481	-178.14
.060	.0763	-.0023	.0764	-1.72	22.3427	-178.28
.055	.0700	-.0019	.0700	-1.58	23.0979	-178.42
.050	.0636	-.0016	.0636	-1.43	23.9251	-178.57
.045	.0573	-.0013	.0573	-1.29	24.8398	-178.71
.040	.0509	-.0010	.0509	-1.15	25.8624	-178.85
.035	.0445	-.0008	.0446	-1.00	27.0218	-179.00
.030	.0382	-.0006	.0382	-.86	28.3604	-179.14
.025	.0318	-.0004	.0318	-.72	29.9437	-179.28
.020	.0255	-.0003	.0255	-.57	31.8817	-179.43
.015	.0191	-.0001	.0191	-.43	34.3802	-179.57
.010	.0127	-.0001	.0127	-.29	37.9019	-179.71
.005	.0064	-.0000	.0064	-.14	43.9224	-179.86

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .2

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
1.000	.6238	-.5093	.8053	-39.23	1.8812	-140.77
.995	.6840	-.5042	.8498	-36.39	1.4138	-143.61
.990	.7067	-.4992	.8652	-35.24	1.2577	-144.76
.985	.7230	-.4941	.8757	-34.35	1.1527	-145.65
.980	.7359	-.4891	.8837	-33.61	1.0743	-146.39
.975	.7467	-.4842	.8899	-32.96	1.0128	-147.04
.970	.7559	-.4792	.8950	-32.37	.9635	-147.63
.965	.7639	-.4743	.8992	-31.83	.9233	-148.17
.960	.7709	-.4694	.9026	-31.34	.8905	-148.66
.955	.7771	-.4645	.9053	-30.87	.8637	-149.13
.950	.7826	-.4596	.9076	-30.43	.8420	-149.57
.945	.7875	-.4548	.9094	-30.01	.8246	-149.99
.940	.7919	-.4500	.9109	-29.61	.8111	-150.39
.935	.7958	-.4452	.9119	-29.23	.8009	-150.77
.930	.7993	-.4405	.9127	-28.86	.7937	-151.14
.925	.8025	-.4358	.9131	-28.50	.7892	-151.50
.920	.8052	-.4311	.9134	-28.16	.7872	-151.84
.915	.8077	-.4264	.9133	-27.83	.7875	-152.17
.910	.8098	-.4218	.9131	-27.51	.7898	-152.49
.905	.8117	-.4171	.9126	-27.20	.7941	-152.80
.900	.8133	-.4125	.9120	-26.89	.8003	-153.11
.895	.8147	-.4080	.9112	-26.60	.8081	-153.40
.890	.8159	-.4034	.9102	-26.31	.8175	-153.69
.885	.8168	-.3989	.9090	-26.03	.8285	-153.97
.880	.8176	-.3944	.9077	-25.75	.8409	-154.25
.875	.8181	-.3899	.9063	-25.48	.8546	-154.52
.870	.8185	-.3855	.9047	-25.22	.8697	-154.78
.865	.8187	-.3811	.9030	-24.96	.8860	-155.04
.860	.8187	-.3767	.9012	-24.71	.9035	-155.29
.855	.8186	-.3723	.8993	-24.46	.9221	-155.54
.850	.8183	-.3680	.8972	-24.21	.9419	-155.79
.845	.8179	-.3637	.8951	-23.97	.9628	-156.03
.840	.8173	-.3594	.8928	-23.73	.9846	-156.27
.835	.8166	-.3551	.8905	-23.50	1.0076	-156.50
.830	.8158	-.3509	.8880	-23.27	1.0314	-156.73
.825	.8148	-.3466	.8855	-23.05	1.0563	-156.95
.820	.8137	-.3425	.8829	-22.82	1.0821	-157.18
.815	.8126	-.3383	.8802	-22.60	1.1087	-157.40
.810	.8112	-.3342	.8774	-22.39	1.1363	-157.61
.805	.8098	-.3300	.8745	-22.17	1.1648	-157.83
.800	.8083	-.3260	.8716	-21.96	1.1941	-158.04
.795	.8067	-.3219	.8685	-21.75	1.2242	-158.25
.790	.8050	-.3179	.8654	-21.55	1.2552	-158.45
.785	.8031	-.3138	.8623	-21.34	1.2870	-158.66
.780	.8012	-.3099	.8591	-21.14	1.3196	-158.86
.775	.7992	-.3059	.8558	-20.94	1.3530	-159.06
.770	.7971	-.3020	.8524	-20.75	1.3872	-159.25
.765	.7949	-.2981	.8490	-20.55	1.4221	-159.45
.760	.7927	-.2942	.8455	-20.36	1.4579	-159.64
.755	.7903	-.2903	.8419	-20.17	1.4943	-159.83

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .2

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.750	.7879	-.2865	.8383	-19.98	1.5316	-160.02
.745	.7854	-.2827	.8347	-19.80	1.5695	-160.20
.740	.7828	-.2789	.8310	-19.61	1.6083	-160.39
.735	.7801	-.2751	.8272	-19.43	1.6477	-160.57
.730	.7774	-.2714	.8234	-19.25	1.6879	-160.75
.725	.7746	-.2677	.8195	-19.07	1.7288	-160.93
.720	.7717	-.2640	.8156	-18.89	1.7705	-161.11
.715	.7687	-.2604	.8116	-18.71	1.8128	-161.29
.710	.7657	-.2567	.8076	-18.54	1.8559	-161.46
.705	.7626	-.2531	.8035	-18.36	1.8998	-161.64
.700	.7595	-.2496	.7994	-18.19	1.9443	-161.81
.695	.7563	-.2460	.7953	-18.02	1.9895	-161.98
.690	.7530	-.2425	.7911	-17.85	2.0355	-162.15
.685	.7497	-.2390	.7868	-17.68	2.0822	-162.32
.680	.7463	-.2355	.7826	-17.51	2.1296	-162.49
.675	.7428	-.2321	.7782	-17.35	2.1778	-162.65
.670	.7393	-.2286	.7739	-17.18	2.2266	-162.82
.665	.7358	-.2252	.7695	-17.02	2.2762	-162.98
.660	.7321	-.2219	.7650	-16.86	2.3265	-163.14
.655	.7285	-.2185	.7605	-16.70	2.3775	-163.30
.650	.7248	-.2152	.7560	-16.54	2.4293	-163.46
.645	.7210	-.2119	.7515	-16.38	2.4818	-163.62
.640	.7171	-.2086	.7469	-16.22	2.5351	-163.78
.635	.7133	-.2054	.7422	-16.06	2.5891	-163.94
.630	.7093	-.2021	.7376	-15.91	2.6438	-164.09
.625	.7054	-.1989	.7329	-15.75	2.6993	-164.25
.620	.7013	-.1958	.7282	-15.60	2.7555	-164.40
.615	.6973	-.1926	.7234	-15.44	2.8125	-164.56
.610	.6932	-.1895	.7186	-15.29	2.8703	-164.71
.605	.6890	-.1864	.7138	-15.14	2.9289	-164.86
.600	.6848	-.1833	.7089	-14.99	2.9882	-165.01
.595	.6805	-.1803	.7040	-14.84	3.0483	-165.16
.590	.6762	-.1773	.6991	-14.69	3.1092	-165.31
.585	.6719	-.1743	.6941	-14.54	3.1709	-165.46
.580	.6675	-.1713	.6892	-14.39	3.2335	-165.61
.575	.6631	-.1684	.6842	-14.25	3.2968	-165.75
.570	.6587	-.1655	.6791	-14.10	3.3610	-165.90
.565	.6542	-.1626	.6741	-13.96	3.4260	-166.04
.560	.6496	-.1597	.6690	-13.81	3.4918	-166.19
.555	.6451	-.1569	.6639	-13.67	3.5585	-166.33
.550	.6404	-.1541	.6587	-13.53	3.6261	-166.47
.545	.6358	-.1513	.6535	-13.38	3.6946	-166.62
.540	.6311	-.1485	.6483	-13.24	3.7639	-166.76
.535	.6264	-.1458	.6431	-13.10	3.8341	-166.90
.530	.6216	-.1431	.6379	-12.96	3.9052	-167.04
.525	.6168	-.1404	.6326	-12.82	3.9773	-167.18
.520	.6120	-.1377	.6273	-12.68	4.0503	-167.32
.515	.6072	-.1351	.6220	-12.54	4.1242	-167.46
.510	.6023	-.1325	.6167	-12.40	4.1991	-167.60
.505	.5973	-.1299	.6113	-12.27	4.2750	-167.73

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .2

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.500	.5924	-.1273	.6059	-12.13	4.3519	-167.87
.495	.5874	-.1248	.6005	-11.99	4.4298	-168.01
.490	.5824	-.1223	.5951	-11.86	4.5087	-168.14
.485	.5773	-.1198	.5896	-11.72	4.5886	-168.28
.480	.5722	-.1173	.5841	-11.59	4.6696	-168.41
.475	.5671	-.1149	.5787	-11.45	4.7516	-168.55
.470	.5620	-.1125	.5731	-11.32	4.8348	-168.68
.465	.5568	-.1101	.5676	-11.19	4.9191	-168.81
.460	.5516	-.1078	.5621	-11.05	5.0044	-168.95
.455	.5464	-.1054	.5565	-10.92	5.0910	-169.08
.450	.5411	-.1031	.5509	-10.79	5.1787	-169.21
.445	.5359	-.1009	.5453	-10.66	5.2676	-169.34
.440	.5306	-.0986	.5396	-10.53	5.3578	-169.47
.435	.5252	-.0964	.5340	-10.40	5.4491	-169.60
.430	.5199	-.0942	.5283	-10.27	5.5418	-169.73
.425	.5145	-.0920	.5227	-10.14	5.6357	-169.86
.420	.5091	-.0898	.5170	-10.01	5.7309	-169.99
.415	.5037	-.0877	.5112	-9.88	5.8275	-170.12
.410	.4982	-.0856	.5055	-9.75	5,9255	-170.25
.405	.4927	-.0835	.4998	-9.62	6.0249	-170.38
.400	.4872	-.0815	.4940	-9.49	6.1257	-170.51
.395	.4817	-.0795	.4882	-9.37	6.2280	-170.63
.390	.4761	-.0775	.4824	-9.24	6.3317	-170.76
.385	.4706	-.0755	.4766	-9.11	6.4371	-170.89
.380	.4650	-.0735	.4708	-8.99	6.5439	-171.01
.375	.4594	-.0716	.4649	-8.86	6.6524	-171.14
.370	.4537	-.0697	.4591	-8.74	6.7626	-171.26
.365	.4481	-.0679	.4532	-8.61	6.8744	-171.39
.360	.4424	-.0660	.4473	-8.49	6.9880	-171.51
.355	.4367	-.0642	.4414	-8.36	7.1033	-171.64
.350	.4310	-.0624	.4355	-8.24	7.2205	-171.76
.345	.4253	-.0606	.4296	-8.11	7.3396	-171.89
.340	.4195	-.0589	.4236	-7.99	7.4606	-172.01
.335	.4137	-.0572	.4177	-7.87	7.5835	-172.13
.330	.4079	-.0555	.4117	-7.74	7.7085	-172.26
.325	.4021	-.0538	.4057	-7.62	7.8356	-172.38
.320	.3963	-.0522	.3997	-7.50	7.9648	-172.50
.315	.3905	-.0505	.3937	-7.37	8.0963	-172.63
.310	.3846	-.0489	.3877	-7.25	8.2300	-172.75
.305	.3787	-.0474	.3817	-7.13	8.3661	-172.87
.300	.3728	-.0458	.3756	-7.01	8.5046	-172.99
.295	.3669	-.0443	.3696	-6.89	8.6457	-173.11
.290	.3610	-.0428	.3635	-6.77	8.7893	-173.23
.285	.3551	-.0414	.3575	-6.65	8.9356	-173.35
.280	.3491	-.0399	.3514	-6.53	9.0846	-173.47
.275	.3431	-.0385	.3453	-6.40	9.2366	-173.60
.270	.3371	-.0371	.3392	-6.28	9.3915	-173.72
.265	.3311	-.0358	.3331	-6.16	9.5494	-173.84
.260	.3251	-.0344	.3269	-6.04	9.7106	-173.96
.255	.3191	-.0331	.3208	-5.93	9.8750	-174.07

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .2

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.250	.3131	-.0318	.3147	-5.81	10.0429	-174.19
.245	.3070	-.0306	.3085	-5.69	10.2143	-174.31
.240	.3009	-.0293	.3024	-5.57	10.3895	-174.43
.235	.2949	-.0281	.2962	-5.45	10.5685	-174.55
.230	.2888	-.0269	.2900	-5.33	10.7515	-174.67
.225	.2827	-.0258	.2838	-5.21	10.9387	-174.79
.220	.2765	-.0247	.2776	-5.09	11.1303	-174.91
.215	.2704	-.0235	.2714	-4.98	11.3265	-175.02
.210	.2643	-.0225	.2652	-4.86	11.5274	-175.14
.205	.2581	-.0214	.2590	-4.74	11.7334	-175.26
.200	.2520	-.0204	.2528	-4.62	11.9446	-175.38
.195	.2458	-.0194	.2466	-4.51	12.1614	-175.49
.190	.2396	-.0184	.2403	-4.39	12.3839	-175.61
.185	.2334	-.0174	.2341	-4.27	12.6125	-175.73
.180	.2272	-.0165	.2278	-4.15	12.8476	-175.85
.175	.2210	-.0156	.2216	-4.04	13.0894	-175.96
.170	.2148	-.0147	.2153	-3.92	13.3385	-176.08
.165	.2086	-.0139	.2090	-3.80	13.5951	-176.20
.160	.2024	-.0130	.2028	-3.69	13.8598	-176.31
.155	.1961	-.0122	.1965	-3.57	14.1331	-176.43
.150	.1899	-.0115	.1902	-3.45	14.4154	-176.55
.145	.1836	-.0107	.1839	-3.34	14.7076	-176.66
.140	.1773	-.0100	.1776	-3.22	15.0101	-176.78
.135	.1711	-.0093	.1713	-3.11	15.3238	-176.89
.130	.1648	-.0086	.1650	-2.99	15.6495	-177.01
.125	.1585	-.0080	.1587	-2.87	15.9882	-177.13
.120	.1522	-.0073	.1524	-2.76	16.3408	-177.24
.115	.1459	-.0067	.1461	-2.64	16.7086	-177.36
.110	.1396	-.0062	.1398	-2.53	17.0930	-177.47
.105	.1333	-.0056	.1334	-2.41	17.4953	-177.59
.100	.1270	-.0051	.1271	-2.30	17.9175	-177.70
.095	.1207	-.0046	.1208	-2.18	18.3615	-177.82
.090	.1143	-.0041	.1144	-2.07	18.8297	-177.93
.085	.1080	-.0037	.1081	-1.95	19.3248	-178.05
.080	.1017	-.0033	.1017	-1.84	19.8500	-178.16
.075	.0954	-.0029	.0954	-1.72	20.4094	-178.28
.070	.0890	-.0025	.0890	-1.61	21.0075	-178.39
.065	.0827	-.0022	.0827	-1.49	21.6502	-178.51
.060	.0763	-.0018	.0763	-1.38	22.3444	-178.62
.055	.0700	-.0015	.0700	-1.26	23.0993	-178.74
.050	.0636	-.0013	.0636	-1.15	23.9263	-178.85
.045	.0573	-.0010	.0573	-1.03	24.8407	-178.97
.040	.0509	-.0008	.0509	-.92	25.8631	-179.08
.035	.0445	-.0006	.0446	-.80	27.0224	-179.20
.030	.0382	-.0005	.0382	-.69	28.3608	-179.31
.025	.0318	-.0003	.0318	-.57	29.9440	-179.43
.020	.0255	-.0002	.0255	-.46	31.8818	-179.54
.015	.0191	-.0001	.0191	-.34	34.3803	-179.66
.010	.0127	-.0001	.0127	-.23	37.9020	-179.77
.005	.0064	-.0000	.0064	-.11	43.9225	-179.89

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .4

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
1.000	.5835	-.3820	.6974	-33.21	3.1306	-146.79
.995	.6444	-.3782	.7471	-30.41	2.5319	-149.59
.990	.6676	-.3744	.7654	-29.28	2.3218	-150.72
.985	.6846	-.3706	.7784	-28.43	2.1756	-151.57
.980	.6981	-.3668	.7886	-27.72	2.0626	-152.28
.975	.7095	-.3631	.7970	-27.10	1.9708	-152.90
.970	.7193	-.3594	.8041	-26.55	1.8942	-153.45
.965	.7278	-.3557	.8101	-26.05	1.8292	-153.95
.960	.7354	-.3520	.8153	-25.58	1.7733	-154.42
.955	.7422	-.3484	.8199	-25.14	1.7249	-154.86
.950	.7483	-.3447	.8239	-24.74	1.6829	-155.26
.945	.7537	-.3411	.8273	-24.35	1.6464	-155.65
.940	.7587	-.3375	.8304	-23.98	1.6146	-156.02
.935	.7631	-.3339	.8330	-23.63	1.5870	-156.37
.930	.7672	-.3304	.8353	-23.30	1.5632	-156.70
.925	.7708	-.3268	.8373	-22.98	1.5428	-157.02
.920	.7741	-.3233	.8389	-22.67	1.5255	-157.33
.915	.7771	-.3198	.8403	-22.37	1.5110	-157.63
.910	.7798	-.3163	.8415	-22.08	1.4990	-157.92
.905	.7822	-.3128	.8424	-21.80	1.4895	-158.20
.900	.7843	-.3094	.8431	-21.53	1.4823	-158.47
.895	.7862	-.3060	.8436	-21.27	1.4772	-158.73
.890	.7878	-.3026	.8439	-21.01	1.4740	-158.99
.885	.7892	-.2992	.8440	-20.76	1.4727	-159.24
.880	.7905	-.2958	.8440	-20.52	1.4732	-159.48
.875	.7915	-.2925	.8438	-20.28	1.4753	-159.72
.870	.7923	-.2891	.8434	-20.05	1.4791	-159.95
.865	.7930	-.2858	.8429	-19.82	1.4844	-160.18
.860	.7935	-.2825	.8423	-19.60	1.4911	-160.40
.855	.7938	-.2792	.8415	-19.38	1.4993	-160.62
.850	.7939	-.2760	.8405	-19.17	1.5088	-160.83
.845	.7940	-.2727	.8395	-18.96	1.5196	-161.04
.840	.7938	-.2695	.8383	-18.75	1.5317	-161.25
.835	.7936	-.2663	.8370	-18.55	1.5450	-161.45
.830	.7931	-.2631	.8357	-18.35	1.5595	-161.65
.825	.7926	-.2600	.8342	-18.16	1.5751	-161.84
.820	.7919	-.2568	.8325	-17.97	1.5918	-162.03
.815	.7912	-.2537	.8308	-17.78	1.6097	-162.22
.810	.7902	-.2506	.8290	-17.60	1.6286	-162.40
.805	.7892	-.2475	.8271	-17.41	1.6485	-162.59
.800	.7881	-.2445	.8251	-17.23	1.6695	-162.77
.795	.7869	-.2414	.8231	-17.06	1.6914	-162.94
.790	.7855	-.2384	.8209	-16.88	1.7143	-163.12
.785	.7841	-.2354	.8186	-16.71	1.7382	-163.29
.780	.7825	-.2324	.8163	-16.54	1.7631	-163.46
.775	.7809	-.2294	.8139	-16.37	1.7888	-163.63
.770	.7791	-.2265	.8114	-16.21	1.8155	-163.79
.765	.7773	-.2235	.8088	-16.04	1.8431	-163.96
.760	.7754	-.2206	.8062	-15.88	1.8715	-164.12
.755	.7734	-.2177	.8034	-15.72	1.9009	-164.28

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .4

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.750	.7713	-.2149	.8007	-15.57	1.9311	-164.43
.745	.7691	-.2120	.7978	-15.41	1.9622	-164.59
.740	.7669	-.2092	.7949	-15.26	1.9941	-164.74
.735	.7645	-.2064	.7919	-15.10	2.0269	-164.90
.730	.7621	-.2036	.7888	-14.95	2.0605	-165.05
.725	.7596	-.2008	.7857	-14.81	2.0950	-165.19
.720	.7570	-.1980	.7825	-14.66	2.1302	-165.34
.715	.7544	-.1953	.7793	-14.51	2.1663	-165.49
.710	.7517	-.1926	.7760	-14.37	2.2032	-165.63
.705	.7489	-.1899	.7726	-14.23	2.2410	-165.77
.700	.7461	-.1872	.7692	-14.08	2.2795	-165.92
.695	.7431	-.1845	.7657	-13.94	2.3189	-166.06
.690	.7402	-.1819	.7622	-13.80	2.3590	-166.20
.685	.7371	-.1792	.7586	-13.67	2.4000	-166.33
.680	.7340	-.1766	.7549	-13.53	2.4417	-166.47
.675	.7308	-.1740	.7512	-13.40	2.4843	-166.60
.670	.7276	-.1715	.7475	-13.26	2.5277	-166.74
.665	.7243	-.1689	.7437	-13.13	2.5719	-166.87
.660	.7209	-.1664	.7399	-13.00	2.6169	-167.00
.655	.7175	-.1639	.7360	-12.87	2.6627	-167.13
.650	.7140	-.1614	.7320	-12.74	2.7092	-167.26
.645	.7105	-.1589	.7281	-12.61	2.7567	-167.39
.640	.7069	-.1565	.7240	-12.48	2.8049	-167.52
.635	.7033	-.1540	.7200	-12.35	2.8539	-167.65
.630	.6996	-.1516	.7158	-12.23	2.9038	-167.77
.625	.6959	-.1492	.7117	-12.10	2.9544	-167.90
.620	.6921	-.1468	.7075	-11.98	3.0059	-168.02
.615	.6882	-.1445	.7032	-11.86	3.0582	-168.14
.610	.6843	-.1421	.6989	-11.73	3.1114	-168.27
.605	.6804	-.1398	.6946	-11.61	3.1654	-168.39
.600	.6764	-.1375	.6902	-11.49	3.2202	-168.51
.595	.6723	-.1352	.6858	-11.37	3.2759	-168.63
.590	.6683	-.1330	.6814	-11.25	3.3325	-168.75
.585	.6641	-.1307	.6769	-11.14	3.3899	-168.86
.580	.6600	-.1285	.6723	-11.02	3.4481	-168.98
.575	.6557	-.1263	.6678	-10.90	3.5073	-169.10
.570	.6515	-.1241	.6632	-10.79	3.5673	-169.21
.565	.6472	-.1219	.6585	-10.67	3.6283	-169.33
.560	.6428	-.1198	.6539	-10.56	3.6901	-169.44
.555	.6384	-.1177	.6492	-10.44	3.7528	-169.56
.550	.6340	-.1155	.6444	-10.33	3.8165	-169.67
.545	.6295	-.1135	.6397	-10.22	3.8811	-169.78
.540	.6250	-.1114	.6348	-10.10	3.9466	-169.90
.535	.6204	-.1093	.6300	-9.99	4.0131	-170.01
.530	.6159	-.1073	.6251	-9.88	4.0805	-170.12
.525	.6112	-.1053	.6202	-9.77	4.1489	-170.23
.520	.6066	-.1033	.6153	-9.66	4.2183	-170.34
.515	.6019	-.1013	.6103	-9.55	4.2887	-170.45
.510	.5971	-.0994	.6053	-9.45	4.3601	-170.55
.505	.5924	-.0974	.6003	-9.34	4.4325	-170.66

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .4

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.500	.5875	-.0955	.5953	-9.23	4.5060	-170.77
.495	.5827	-.0936	.5902	-9.13	4.5805	-170.87
.490	.5778	-.0917	.5851	-9.02	4.6561	-170.98
.485	.5729	-.0899	.5799	-8.91	4.7328	-171.09
.480	.5680	-.0880	.5747	-8.81	4.8105	-171.19
.475	.5630	-.0862	.5695	-8.70	4.8894	-171.30
.470	.5580	-.0844	.5643	-8.60	4.9694	-171.40
.465	.5529	-.0826	.5591	-8.50	5.0506	-171.50
.460	.5479	-.0808	.5538	-8.39	5.1330	-171.61
.455	.5428	-.0791	.5485	-8.29	5.2165	-171.71
.450	.5376	-.0774	.5432	-8.19	5.3013	-171.81
.445	.5325	-.0756	.5378	-8.09	5.3873	-171.91
.440	.5273	-.0740	.5324	-7.98	5.4746	-172.02
.435	.5221	-.0723	.5270	-7.88	5.5631	-172.12
.430	.5168	-.0706	.5216	-7.78	5.6530	-172.22
.425	.5115	-.0690	.5162	-7.68	5.7442	-172.32
.420	.5062	-.0674	.5107	-7.58	5.8367	-172.42
.415	.5009	-.0658	.5052	-7.48	5.9307	-172.52
.410	.4955	-.0642	.4997	-7.38	6.0260	-172.62
.405	.4902	-.0627	.4942	-7.28	6.1228	-172.72
.400	.4848	-.0611	.4886	-7.19	6.2211	-172.81
.395	.4793	-.0596	.4830	-7.09	6.3208	-172.91
.390	.4739	-.0581	.4774	-6.99	6.4221	-173.01
.385	.4684	-.0566	.4718	-6.89	6.5250	-173.11
.380	.4629	-.0552	.4661	-6.80	6.6295	-173.20
.375	.4573	-.0537	.4605	-6.70	6.7357	-173.30
.370	.4518	-.0523	.4548	-6.60	6.8435	-173.40
.365	.4462	-.0509	.4491	-6.51	6.9531	-173.49
.360	.4406	-.0495	.4434	-6.41	7.0644	-173.59
.355	.4350	-.0481	.4376	-6.32	7.1776	-173.68
.350	.4293	-.0468	.4319	-6.22	7.2926	-173.78
.345	.4237	-.0455	.4261	-6.13	7.4095	-173.87
.340	.4180	-.0442	.4203	-6.03	7.5284	-173.97
.335	.4123	-.0429	.4145	-5.94	7.6493	-174.06
.330	.4066	-.0416	.4087	-5.84	7.7723	-174.16
.325	.4008	-.0403	.4028	-5.75	7.8973	-174.25
.320	.3950	-.0391	.3970	-5.65	8.0246	-174.35
.315	.3893	-.0379	.3911	-5.56	8.1542	-174.44
.310	.3835	-.0367	.3852	-5.47	8.2860	-174.53
.305	.3776	-.0355	.3793	-5.38	8.4203	-174.62
.300	.3718	-.0344	.3734	-5.28	8.5570	-174.72
.295	.3659	-.0332	.3674	-5.19	8.6962	-174.81
.290	.3601	-.0321	.3615	-5.10	8.8381	-174.90
.285	.3542	-.0310	.3555	-5.01	8.9827	-174.99
.280	.3483	-.0299	.3495	-4.91	9.1301	-175.09
.275	.3423	-.0289	.3435	-4.82	9.2803	-175.18
.270	.3364	-.0278	.3375	-4.73	9.4336	-175.27
.265	.3304	-.0268	.3315	-4.64	9.5900	-175.36
.260	.3245	-.0258	.3255	-4.55	9.7496	-175.45
.255	.3185	-.0248	.3194	-4.46	9.9125	-175.54

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .4

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.250	.3125	-.0239	.3134	-4.37	10.0789	-175.63
.245	.3064	-.0229	.3073	-4.28	10.2489	-175.72
.240	.3004	-.0220	.3012	-4.19	10.4226	-175.81
.235	.2944	-.0211	.2951	-4.10	10.6002	-175.90
.230	.2883	-.0202	.2890	-4.01	10.7819	-175.99
.225	.2822	-.0193	.2829	-3.92	10.9678	-176.08
.220	.2761	-.0185	.2768	-3.83	11.1581	-176.17
.215	.2700	-.0177	.2706	-3.74	11.3530	-176.26
.210	.2639	-.0168	.2645	-3.65	11.5527	-176.35
.205	.2578	-.0161	.2583	-3.56	11.7575	-176.44
.200	.2517	-.0153	.2521	-3.47	11.9675	-176.53
.195	.2455	-.0145	.2459	-3.39	12.1831	-176.61
.190	.2394	-.0138	.2398	-3.30	12.4045	-176.70
.185	.2332	-.0131	.2336	-3.21	12.6321	-176.79
.180	.2270	-.0124	.2274	-3.12	12.8661	-176.88
.175	.2208	-.0117	.2211	-3.03	13.1069	-176.97
.170	.2146	-.0110	.2149	-2.94	13.3549	-177.06
.165	.2084	-.0104	.2087	-2.86	13.6106	-177.14
.160	.2022	-.0098	.2024	-2.77	13.8744	-177.23
.155	.1960	-.0092	.1962	-2.68	14.1467	-177.32
.150	.1897	-.0086	.1899	-2.59	14.4282	-177.41
.145	.1835	-.0080	.1837	-2.51	14.7195	-177.49
.140	.1772	-.0075	.1774	-2.42	15.0212	-177.58
.135	.1710	-.0070	.1711	-2.33	15.3342	-177.67
.130	.1647	-.0065	.1648	-2.24	15.6591	-177.76
.125	.1584	-.0060	.1585	-2.16	15.9970	-177.84
.120	.1521	-.0055	.1522	-2.07	16.3490	-177.93
.115	.1459	-.0051	.1459	-1.98	16.7161	-178.02
.110	.1396	-.0046	.1396	-1.90	17.0998	-178.10
.105	.1333	-.0042	.1333	-1.81	17.5016	-178.19
.100	.1270	-.0038	.1270	-1.72	17.9232	-178.28
.095	.1206	-.0034	.1207	-1.64	18.3666	-178.36
.090	.1143	-.0031	.1144	-1.55	18.8342	-178.45
.085	.1080	-.0028	.1080	-1.46	19.3289	-178.54
.080	.1017	-.0024	.1017	-1.38	19.8537	-178.62
.075	.0953	-.0021	.0954	-1.29	20.4126	-178.71
.070	.0890	-.0019	.0890	-1.20	21.0103	-178.80
.065	.0827	-.0016	.0827	-1.12	21.6526	-178.88
.060	.0763	-.0014	.0763	-1.03	22.3465	-178.97
.055	.0700	-.0012	.0700	-.95	23.1010	-179.05
.050	.0636	-.0010	.0636	-.86	23.9277	-179.14
.045	.0573	-.0008	.0573	-.77	24.8419	-179.23
.040	.0509	-.0006	.0509	-.69	25.8640	-179.31
.035	.0445	-.0005	.0445	-.60	27.0231	-179.40
.030	.0382	-.0003	.0382	-.52	28.3613	-179.48
.025	.0318	-.0002	.0318	-.43	29.9443	-179.57
.020	.0255	-.0002	.0255	-.34	31.8821	-179.66
.015	.0191	-.0001	.0191	-.26	34.3805	-179.74
.010	.0127	-.0000	.0127	-.17	37.9020	-179.83
.005	.0064	-.0000	.0064	-.09	43.9225	-179.91

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .6

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
1.000	.5093	-.2547	.5694	-26.57	4.8915	-153.43
.995	.5714	-.2521	.6246	-23.81	4.0883	-156.19
.990	.5959	-.2496	.6461	-22.72	3.7943	-157.28
.985	.6140	-.2471	.6619	-21.92	3.5843	-158.08
.980	.6288	-.2446	.6747	-21.25	3.4181	-158.75
.975	.6413	-.2421	.6855	-20.68	3.2798	-159.32
.970	.6523	-.2396	.6949	-20.17	3.1616	-159,83
.965	.6620	-.2371	.7032	-19.71	3.0586	-160.29
.960	.6707	-.2347	.7106	-19.29	2.9677	-160.71
.955	.6786	-.2322	.7172	-18.89	2.8867	-161.11
.950	.6858	-.2298	.7233	-18.53	2.8142	-161.47
.945	.6923	-.2274	.7287	-18.18	2.7489	-161.82
.940	.6983	-.2250	.7337	-17.86	2.6898	-162.14
.935	.7038	-.2226	.7382	-17.55	2.6363	-162.45
.930	.7089	-.2202	.7424	-17.26	2.5878	-162.74
.925	.7136	-.2179	.7461	-16.98	2.5437	-163.02
.920	.7179	-.2155	.7496	-16.71	2.5037	-163.29
.915	.7219	-.2132	.7527	-16.45	2.4674	-163.55
.910	.7255	-.2109	.7556	-16.21	2,4345	-163.79
.905	.7289	-.2086	.7582	-15.97	2.4048	-164.03
.900	.7320	-.2063	.7605	-15.74	2.3781	-164.26
.895	.7348	-.2040	.7626	-15.51	2.3541	-164.49
.890	.7374	-.2017	.7645	-15.30	2.3327	-164.70
.885	.7397	-.1994	.7662	-15.09	2.3137	-164.91
.880	.7419	-.1972	.7676	-14.89	2.2970	-165.11
.875	.7438	-.1950	.7689	-14.69	2.2825	-165.31
.870	.7455	-.1927	.7700	-14.50	2.2701	-165.50
.865	.7470	-.1905	.7709	-14.31	2.2597	-165.69
.860	.7484	-.1883	.7717	-14.13	2.2511	-165.87
.855	.7495	-.1862	.7723	-13.95	2.2443	-166.05
.850	.7505	-.1840	.7727	-13.77	2.2393	-166.23
.845	.7514	-.1818	.7730	-13.60	2.2359	-166.40
.840	.7520	-.1797	.7732	-13.44	2.2342	-166.56
.835	.7526	-.1775	.7732	-13.28	2.2340	-166.72
.830	.7529	-.1754	.7731	-13.12	2.2353	-166.88
.825	.7532	-.1733	.7729	-12.96	2.2381	-167.04
.820	.7533	-.1712	.7725	-12.81	2.2422	-167.19
.815	.7532	-.1691	.7720	-12.66	2.2478	-167.34
.810	.7531	-.1671	.7714	-12.51	2.2546	-167.49
.805	.7528	-.1650	.7707	-12.36	2.2628	-167.64
.800	.7524	-.1630	.7698	-12.22	2.2723	-167.78
.795	.7518	-.1609	.7689	-12.08	2.2829	-167.92
.790	.7512	-.1589	.7678	-11.95	2.2948	-168.05
.785	.7504	-.1569	.7667	-11.81	2.3079	-168.19
.780	.7496	-.1549	.7654	-11.68	2.3221	-168.32
.775	.7486	-.1530	.7641	-11.55	2.3375	-168.45
.770	.7475	-.1510	.7626	-11.42	2.3540	-168.58
.765	.7463	-.1490	.7611	-11.29	2.3715	-168.71
.760	.7451	-.1471	.7594	-11.17	2.3902	-168.83
.755	.7437	-.1452	.7577	-11.04	2.4099	-168.96

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .6

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.750	.7422	-.1432	.7559	-10.92	2.4307	-169.08
.745	.7406	-.1413	.7540	-10.80	2.4525	-169.20
.740	.7390	-.1394	.7520	-10.69	2.4754	-169.31
.735	.7372	-.1376	.7500	-10.57	2.4992	-169.43
.730	.7354	-.1357	.7478	-10.46	2.5241	-169.54
.725	.7335	-.1339	.7456	-10.34	2.5499	-169.66
.720	.7315	-.1320	.7433	-10.23	2.5767	-169.77
.715	.7294	-.1302	.7409	-10.12	2.6045	-169.88
.710	.7272	-.1284	.7385	-10.01	2.6333	-169.99
.705	.7250	-.1266	.7360	-9.90	2.6630	-170.10
.700	.7227	-.1248	.7334	-9.80	2.6936	-170.20
.695	.7203	-.1230	.7307	-9.69	2.7252	-170.31
.690	.7178	-.1212	.7280	-9.59	2.7578	-170.41
.685	.7153	-.1195	.7252	-9.48	2.7912	-170.52
.680	.7126	-.1178	.7223	-9.38	2.8256	-170.62
.675	.7100	-.1160	.7194	-9.28	2.8609	-170.72
.670	.7072	-.1143	.7164	-9.18	2.8972	-170.82
.665	.7044	-.1126	.7133	-9.08	2.9344	-170.92
.660	.7015	-.1109	.7102	-8.99	2.9724	-171.01
.655	.6985	-.1093	.7070	-8.89	3.0115	-171.11
.650	.6955	-.1076	.7038	-8.79	3.0514	-171.21
.645	.6924	-.1059	.7005	-8.70	3.0922	-171.30
.640	.6893	-.1043	.6971	-8.61	3.1340	-171.39
.635	.6861	-.1027	.6937	-8.51	3.1766	-171.49
.630	.6828	-.1011	.6902	-8.42	3.2202	-171.58
.625	.6795	-.0995	.6867	-8.33	3.2647	-171.67
.620	.6761	-.0979	.6831	-8.24	3.3102	-171.76
.615	.6726	-.0963	.6795	-8.15	3.3565	-171.85
.610	.6691	-.0948	.6758	-8.06	3.4038	-171.94
.605	.6656	-.0932	.6720	-7.97	3.4520	-172.03
.600	.6619	-.0917	.6683	-7.89	3.5011	-172.11
.595	.6583	-.0902	.6644	-7.80	3.5512	-172.20
.590	.6545	-.0886	.6605	-7.71	3.6022	-172.29
.585	.6508	-.0871	.6566	-7.63	3.6542	-172.37
.580	.6469	-.0857	.6526	-7.54	3.7071	-172.46
.575	.6431	-.0842	.6486	-7.46	3.7610	-172.54
.570	.6391	-.0827	.6445	-7.38	3.8158	-172.62
.565	.6352	-.0813	.6403	-7.29	3.8717	-172.71
.560	.6311	-.0799	.6362	-7.21	3.9285	-172.79
.555	.6271	-.0784	.6320	-7.13	3.9862	-172.87
.550	.6230	-.0770	.6277	-7.05	4.0450	-172.95
.545	.6188	-.0756	.6234	-6.97	4.1048	-173.03
.540	.6146	-.0743	.6190	-6.89	4.1656	-173.11
.535	.6103	-.0729	.6147	-6.81	4.2274	-173.19
.530	.6060	-.0715	.6102	-6.73	4.2902	-173.27
.525	.6017	-.0702	.6058	-6.65	4.3541	-173.35
.520	.5973	-.0689	.6012	-6.58	4.4191	-173.42
.515	.5929	-.0675	.5967	-6.50	4.4851	-173.50
.510	.5884	-.0662	.5921	-6.42	4.5522	-173.58
.505	.5839	-.0649	.5875	-6.35	4.6203	-173.65

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .6

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.500	.5793	-.0637	.5828	-6.27	4.6896	-173.73
.495	.5747	-.0624	.5781	-6.20	4.7600	-173.80
.490	.5701	-.0611	.5734	-6.12	4.8315	-173.88
.485	.5654	-.0599	.5686	-6.05	4.9042	-173.95
.480	.5607	-.0587	.5638	-5.97	4.9780	-174.03
.475	.5560	-.0575	.5589	-5.90	5.0531	-174.10
.470	.5512	-.0563	.5540	-5.83	5.1293	-174.17
.465	.5463	-.0551	.5491	-5.76	5.2067	-174.24
.460	.5415	-.0539	.5442	-5.68	5.2854	-174.32
.455	.5366	-.0527	.5392	-5.61	5.3653	-174.39
.450	.5317	-.0516	.5342	-5.54	5.4465	-174.46
.445	.5267	-.0504	.5291	-5.47	5.5289	-174.53
.440	.5217	-.0493	.5240	-5.40	5.6127	-174.60
.435	.5167	-.0482	.5189	-5.33	5.6979	-174.67
.430	.5116	-.0471	.5138	-5.26	5.7843	-174.74
.425	.5065	-.0460	.5086	-5.19	5.8722	-174.81
.420	.5014	-.0449	.5034	-5.12	5.9615	-174.88
.415	.4962	-.0439	.4982	-5.05	6.0522	-174.95
.410	.4911	-.0428	.4929	-4.98	6.1444	-175.02
.405	.4858	-.0418	.4876	-4.91	6.2381	-175.09
.400	.4806	-.0407	.4823	-4.85	6.3333	-175.15
.395	.4753	-.0397	.4770	-4.78	6.4301	-175.22
.390	.4700	-.0387	.4716	-4.71	6.5285	-175.29
.385	.4647	-.0377	.4662	-4.64	6.6285	-175.36
.380	.4593	-.0368	.4608	-4.58	6.7301	-175.42
.375	.4539	-.0358	.4553	-4.51	6.8334	-175.49
.370	.4485	-.0349	.4499	-4.44	6.9385	-175.56
.365	.4431	-.0339	.4444	-4.38	7.0454	-175.62
.360	.4376	-.0330	.4388	-4.31	7.1540	-175.69
.355	.4321	-.0321	.4333	-4.25	7.2646	-175.75
.350	.4266	-.0312	.4277	-4.18	7.3770	-175.82
.345	.4210	-.0303	.4221	-4.12	7.4914	-175.88
.340	.4155	-.0294	.4165	-4.05	7.6078	-175.95
.335	.4099	-.0286	.4109	-3.99	7.7262	-176.01
.330	.4042	-.0277	.4052	-3.92	7.8468	-176.08
.325	.3986	-.0269	.3995	-3.86	7.9696	-176.14
.320	.3929	-.0261	.3938	-3.80	8.0945	-176.20
.315	.3872	-.0253	.3881	-3.73	8.2218	-176.27
.310	.3815	-.0245	.3823	-3.67	8.3514	-176.33
.305	.3758	-.0237	.3766	-3.61	8.4835	-176.39
.300	.3701	-.0229	.3708	-3.54	8.6181	-176.46
.295	.3643	-.0222	.3650	-3.48	8.7552	-176.52
.290	.3585	-.0214	.3591	-3.42	8.8950	-176.58
.285	.3527	-.0207	.3533	-3.36	9.0376	-176.64
.280	.3468	-.0200	.3474	-3.29	9.1830	-176.71
.275	.3410	-.0193	.3415	-3.23	9.3313	-176.77
.270	.3351	-.0186	.3356	-3.17	9.4827	-176.83
.265	.3292	-.0179	.3297	-3.11	9.6372	-176.89
.260	.3233	-.0172	.3238	-3.05	9.7950	-176.95
.255	.3174	-.0166	.3178	-2.99	9.9561	-177.01

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .6

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.250	.3115	-.0159	.3119	-2.93	10.1208	-177.07
.245	.3055	-.0153	.3059	-2.86	10.2891	-177.14
.240	.2995	-.0147	.2999	-2.80	10.4611	-177.20
.235	.2935	-.0141	.2939	-2.74	10.6371	-177.26
.230	.2875	-.0135	.2878	-2.68	10.8172	-177.32
.225	.2815	-.0129	.2818	-2.62	11.0015	-177.38
.220	.2755	-.0123	.2757	-2.56	11.1903	-177.44
.215	.2694	-.0118	.2697	-2.50	11.3837	-177.50
.210	.2633	-.0112	.2636	-2.44	11.5820	-177.56
.205	.2573	-.0107	.2575	-2.38	11.7854	-177.62
.200	.2512	-.0102	.2514	-2.32	11.9940	-177.68
.195	.2450	-.0097	.2452	-2.26	12.2083	-177.74
.190	.2389	-.0092	.2391	-2.20	12.4284	-177.80
.185	.2328	-.0087	.2330	-2.14	12.6547	-177.86
.180	.2266	-.0083	.2268	-2.09	12.8875	-177.91
.175	.2205	-.0078	.2206	-2.03	13.1271	-177.97
.170	.2143	-.0074	.2144	-1.97	13.3740	-178.03
.165	.2081	-.0069	.2082	-1.91	13.6286	-178.09
.160	.2019	-.0065	.2020	-1.85	13.8912	-178.15
.155	.1957	-.0061	.1958	-1.79	14.1625	-178.21
.150	.1895	-.0057	.1896	-1.73	14.4430	-178.27
.145	.1833	-.0054	.1834	-1.67	14.7333	-178.33
.140	.1771	-.0050	.1771	-1.61	15.0341	-178.39
.135	.1708	-.0046	.1709	-1.56	15.3461	-178.44
.130	.1646	-.0043	.1646	-1.50	15.6702	-178.50
.125	.1583	-.0040	.1584	-1.44	16.0073	-178.56
.120	.1520	-.0037	.1521	-1.38	16.3584	-178.62
.115	.1458	-.0034	.1458	-1.32	16.7248	-178.68
.110	.1395	-.0031	.1395	-1.27	17.1077	-178.73
.105	.1332	-.0028	.1332	-1.21	17.5088	-178.79
.100	.1269	-.0025	.1269	-1.15	17.9297	-178.85
.095	.1206	-.0023	.1206	-1.09	18.3725	-178.91
.090	.1143	-.0021	.1143	-1.03	18.8395	-178.97
.085	.1080	-.0018	.1080	-.98	19.3336	-179.02
.080	.1016	-.0016	.1017	-.92	19.8578	-179.08
.075	.0953	-.0014	.0953	-.86	20.4163	-179.14
.070	.0890	-.0012	.0890	-.80	21.0135	-179.20
.065	.0826	-.0011	.0826	-.75	21.6553	-179.25
.060	.0763	-.0009	.0763	-.69	22.3488	-179.31
.055	.0700	-.0008	.0700	-.63	23.1030	-179.37
.050	.0636	-.0006	.0636	-.57	23.9294	-179.43
.045	.0573	-.0005	.0573	-.52	24.8432	-179.48
.040	.0509	-.0004	.0509	-.46	25.8651	-179.54
.035	.0445	-.0003	.0445	-.40	27.0239	-179.60
.030	.0382	-.0002	.0382	-.34	28.3619	-179.66
.025	.0318	-.0002	.0318	-.29	29.9448	-179.71
.020	.0255	-.0001	.0255	-.23	31.8823	-179.77
.015	.0191	-.0001	.0191	-.17	34.3806	-179.83
.010	.0127	-.0000	.0127	-.11	37.9021	-179.89
.005	.0064	-.0000	.0064	-.06	43.9225	-179.94

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .8

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
1.000	.3820	-.1273	.4026	-18.44	7.9017	-161.56
.995	.4467	-.1261	.4641	-15.76	6.6672	-164.24
.990	.4737	-.1248	.4899	-14.76	6.1986	-165.24
.985	.4943	-.1235	.5095	-14.03	5.8574	-165.97
.980	.5114	-.1223	.5259	-13.45	5.5827	-166.55
.975	.5263	-.1210	.5401	-12.95	5.3507	-167.05
.970	.5396	-.1198	.5528	-12.52	5.1494	-167.48
.965	.5516	-.1186	.5642	-12.13	4.9714	-167.87
.960	.5625	-.1173	.5746	-11.78	4.8120	-168.22
.955	.5726	-.1161	.5843	-11.46	4.6679	-168.54
.950	.5819	-.1149	.5932	-11.17	4.5367	-168.83
.945	.5906	-.1137	.6014	-10.90	4.4166	-169.10
.940	.5986	-.1125	.6091	-10.64	4.3061	-169.36
.935	.6062	-.1113	.6163	-10.41	4.2042	-169.59
.930	.6132	-.1101	.6230	-10.18	4.1099	-169.82
.925	.6198	-.1089	.6293	-9.97	4.0224	-170.03
.920	.6260	-.1078	.6353	-9.77	3.9411	-170.23
.915	.6319	-.1066	.6408	-9.58	3.8654	-170.42
.910	.6374	-.1054	.6460	-9.39	3.7950	-170.61
.905	.6425	-.1043	.6509	-9.22	3.7293	-170.78
.900	.6474	-.1031	.6555	-9.05	3.6682	-170.95
.895	.6519	-.1020	.6598	-8.89	3.6111	-171.11
.890	.6562	-.1009	.6639	-8.74	3.5580	-171.26
.885	.6602	-.0997	.6677	-8.59	3.5084	-171.41
.880	.6640	-.0986	.6712	-8.45	3.4623	-171.55
.875	.6675	-.0975	.6746	-8.31	3.4195	-171.69
.870	.6708	-.0964	.6777	-8.18	3.3797	-171.82
.865	.6738	-.0953	.6805	-8.05	3.3428	-171.95
.860	.6767	-.0942	.6832	-7.92	3.3087	-172.08
.855	.6794	-.0931	.6857	-7.80	3.2772	-172.20
.850	.6818	-.0920	.6880	-7.68	3.2483	-172.32
.845	.6841	-.0909	.6901	-7.57	3.2217	-172.43
.840	.6862	-.0898	.6920	-7.46	3.1975	-172.54
.835	.6881	-.0888	.6938	-7.35	3.1755	-172.65
.830	.6898	-.0877	.6954	-7.25	3.1557	-172.75
.825	.6914	-.0867	.6968	-7.14	3.1379	-172.86
.820	.6928	-.0856	.6981	-7.04	3.1221	-172.96
.815	.6940	-.0846	.6992	-6.95	3.1082	-173.05
.810	.6951	-.0835	.7002	-6.85	3.0962	-173.15
.805	.6961	-.0825	.7010	-6.76	3.0860	-173.24
.800	.6969	-.0815	.7017	-6.67	3.0775	-173.33
.795	.6976	-.0805	.7022	-6.58	3.0708	-173.42
.790	.6981	-.0795	.7026	-6.49	3.0657	-173.51
.785	.6985	-.0785	.7029	-6.41	3.0622	-173.59
.780	.6988	-.0775	.7030	-6.33	3.0603	-173.67
.775	.6989	-.0765	.7031	-6.24	3.0599	-173.76
.770	.6989	-.0755	.7030	-6.16	3.0611	-173.84
.765	.6988	-.0745	.7028	-6.09	3.0637	-173.91
.760	.6986	-.0735	.7024	-6.01	3.0677	-173.99
.755	.6982	-.0726	.7020	-5.93	3.0732	-174.07

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .8

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.750	.6978	-.0716	.7015	-5.86	3.0800	-174.14
.745	.6972	-.0707	.7008	-5.79	3.0882	-174.21
.740	.6965	-.0697	.7000	-5.72	3.0978	-174.28
.735	.6958	-.0688	.6991	-5.65	3.1086	-174.35
.730	.6949	-.0679	.6982	-5.58	3.1207	-174.42
.725	.6939	-.0669	.6971	-5.51	3.1341	-174.49
.720	.6928	-.0660	.6959	-5.44	3.1488	-174.56
.715	.6916	-.0651	.6947	-5.38	3.1647	-174.62
.710	.6903	-.0642	.6933	-5.31	3.1818	-174.69
.705	.6889	-.0633	.6918	-5.25	3.2001	-174.75
.700	.6875	-.0624	.6903	-5.19	3.2195	-174.81
.695	.6859	-.0615	.6886	-5.12	3.2402	-174.88
.690	.6842	-.0606	.6869	-5.06	3.2620	-174.94
.685	.6825	-.0597	.6851	-5.00	3.2850	-175.00
.680	.6806	-.0589	.6832	-4.94	3.3091	-175.06
.675	.6787	-.0580	.6812	-4.89	3.3344	-175.11
.670	.6767	-.0572	.6791	-4.83	3.3608	-175.17
.665	.6746	-.0563	.6770	-4.77	3.3883	-175.23
.660	.6725	-.0555	.6748	-4.71	3.4169	-175.29
.655	.6702	-.0546	.6725	-4.66	3.4466	-175.34
.650	.6679	-.0538	.6701	-4.60	3.4774	-175.40
.645	.6655	-.0530	.6676	-4.55	3.5093	-175.45
.640	.6630	-.0522	.6651	-4.50	3.5423	-175.50
.635	.6605	-.0513	.6625	-4.44	3.5764	-175.56
.630	.6579	-.0505	.6598	-4.39	3.6116	-175.61
.625	.6552	-.0497	.6571	-4.34	3.6478	-175.66
.620	.6524	-.0489	.6542	-4.29	3.6851	-175.71
.615	.6496	-.0482	.6514	-4.24	3.7235	-175.76
.610	.6467	-.0474	.6484	-4.19	3.7630	-175.81
.605	.6437	-.0466	.6454	-4.14	3.8035	-175.86
.600	.6407	-.0458	.6423	-4.09	3.8451	-175.91
.595	.6376	-.0451	.6392	-4.04	3.8878	-175.96
.590	.6344	-.0443	.6359	-4.00	3.9316	-176.00
.585	.6312	-.0436	.6327	-3.95	3.9765	-176.05
.580	.6279	-.0428	.6293	-3.90	4.0224	-176.10
.575	.6245	-.0421	.6259	-3.86	4.0694	-176.14
.570	.6211	-.0414	.6225	-3.81	4.1175	-176.19
.565	.6176	-.0406	.6190	-3.77	4.1667	-176.23
.560	.6141	-.0399	.6154	-3.72	4.2170	-176.28
.555	.6105	-.0392	.6118	-3.68	4.2684	-176.32
.550	.6069	-.0385	.6081	-3.63	4.3209	-176.37
.545	.6031	-.0378	.6043	-3.59	4.3745	-176.41
.540	.5994	-.0371	.6005	-3.54	4.4293	-176.46
.535	.5956	-.0364	.5967	-3.50	4.4851	-176.50
.530	.5917	-.0358	.5928	-3.46	4.5421	-176.54
.525	.5878	-.0351	.5888	-3.42	4.6003	-176.58
.520	.5838	-.0344	.5848	-3.38	4.6596	-176.62
.515	.5798	-.0338	.5808	-3.33	4.7201	-176.67
.510	.5757	-.0331	.5767	-3.29	4.7817	-176.71
.505	.5716	-.0325	.5725	-3.25	4.8445	-176.75

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .8

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.500	.5674	-.0318	.5683	-3.21	4.9086	-176.79
.495	.5632	-.0312	.5640	-3.17	4.9738	-176.83
.490	.5589	-.0306	.5597	-3.13	5.0403	-176.87
.485	.5546	-.0300	.5554	-3.09	5.1080	-176.91
.480	.5502	-.0293	.5510	-3.05	5.1769	-176.95
.475	.5458	-.0287	.5466	-3.01	5.2471	-176.99
.470	.5414	-.0281	.5421	-2.97	5.3186	-177.03
.465	.5369	-.0275	.5376	-2.94	5.3914	-177.06
.460	.5323	-.0269	.5330	-2.90	5.4655	-177.10
.455	.5277	-.0264	.5284	-2.86	5.5409	-177.14
.450	.5231	-.0258	.5237	-2.82	5.6177	-177.18
.445	.5184	-.0252	.5190	-2.78	5.6958	-177.22
.440	.5137	-.0247	.5143	-2.75	5.7754	-177.25
.435	.5090	-.0241	.5095	-2.71	5.8563	-177.29
.430	.5042	-.0235	.5047	-2.67	5.9387	-177.33
.425	.4994	-.0230	.4999	-2.64	6.0226	-177.36
.420	.4945	-.0225	.4950	-2.60	6.1079	-177.40
.415	.4896	-.0219	.4901	-2.56	6.1948	-177.44
.410	.4846	-.0214	.4851	-2.53	6.2831	-177.47
.405	.4797	-.0209	.4801	-2.49	6.3731	-177.51
.400	.4746	-.0204	.4751	-2.46	6.4646	-177.54
.395	.4696	-.0199	.4700	-2.42	6.5578	-177.58
.390	.4645	-.0194	.4649	-2.39	6.6526	-177.61
.385	.4594	-.0189	.4598	-2.35	6.7491	-177.65
.380	.4542	-.0184	.4546	-2.32	6.8473	-177.68
.375	.4490	-.0179	.4494	-2.28	6.9473	-177.72
.370	.4438	-.0174	.4442	-2.25	7.0490	-177.75
.365	.4386	-.0170	.4389	-2.22	7.1527	-177.78
.360	.4333	-.0165	.4336	-2.18	7.2581	-177.82
.355	.4280	-.0160	.4283	-2.15	7.3656	-177.85
.350	.4226	-.0156	.4229	-2.11	7.4749	-177.89
.345	.4173	-.0152	.4175	-2.08	7.5863	-177.92
.340	.4118	-.0147	.4121	-2.05	7.6998	-177.95
.335	.4064	-.0143	.4067	-2.01	7.8153	-177.99
.330	.4009	-.0139	.4012	-1.98	7.9331	-178.02
.325	.3955	-.0135	.3957	-1.95	8.0530	-178.05
.320	.3899	-.0130	.3902	-1.92	8.1753	-178.08
.315	.3844	-.0126	.3846	-1.88	8.2999	-178.12
.310	.3788	-.0122	.3790	-1.85	8.4269	-178.15
.305	.3732	-.0118	.3734	-1.82	8.5564	-178.18
.300	.3676	-.0115	.3678	-1.79	8.6884	-178.21
.295	.3619	-.0111	.3621	-1.75	8.8231	-178.25
.290	.3563	-.0107	.3564	-1.72	8.9605	-178.28
.285	.3506	-.0103	.3507	-1.69	9.1007	-178.31
.280	.3448	-.0100	.3450	-1.66	9.2438	-178.34
.275	.3391	-.0096	.3392	-1.63	9.3899	-178.37
.270	.3333	-.0093	.3335	-1.60	9.5391	-178.40
.265	.3275	-.0089	.3277	-1.56	9.6914	-178.44
.260	.3217	-.0086	.3218	-1.53	9.8471	-178.47
.255	.3159	-.0083	.3160	-1.50	10.0062	-178.50

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B = .8

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.250	.3100	-.0080	.3101	-1.47	10.1688	-178.53
.245	.3042	-.0076	.3043	-1.44	10.3351	-178.56
.240	.2983	-.0073	.2984	-1.41	10.5052	-178.59
.235	.2924	-.0070	.2924	-1.38	10.6793	-178.62
.230	.2864	-.0067	.2865	-1.35	10.8576	-178.65
.225	.2805	-.0064	.2805	-1.32	11.0401	-178.68
.220	.2745	-.0062	.2746	-1.29	11.2271	-178.71
.215	.2685	-.0059	.2686	-1.26	11.4189	-178.74
.210	.2625	-.0056	.2626	-1.23	11.6155	-178.77
.205	.2565	-.0054	.2565	-1.20	11.8172	-178.80
.200	.2504	-.0051	.2505	-1.17	12.0243	-178.83
.195	.2444	-.0048	.2444	-1.14	12.2370	-178.86
.190	.2383	-.0046	.2384	-1.11	12.4557	-178.89
.185	.2322	-.0044	.2323	-1.08	12.6805	-178.92
.180	.2261	-.0041	.2262	-1.05	12.9119	-178.95
.175	.2200	-.0039	.2200	-1.02	13.1502	-178.98
.170	.2139	-.0037	.2139	-.99	13.3957	-179.01
.165	.2077	-.0035	.2078	-.96	13.6490	-179.04
.160	.2016	-.0033	.2016	-.93	13.9104	-179.07
.155	.1954	-.0031	.1954	-.90	14.1805	-179.10
.150	.1892	-.0029	.1892	-.87	14.4599	-179.13
.145	.1830	-.0027	.1830	-.84	14.7491	-179.16
.140	.1768	-.0025	.1768	-.81	15.0488	-179.19
.135	.1706	-.0023	.1706	-.78	15.3597	-179.22
.130	.1644	-.0022	.1644	-.75	15.6828	-179.25
.125	.1581	-.0020	.1581	-.72	16.0189	-179.28
.120	.1519	-.0018	.1519	-.69	16.3692	-179.31
.115	.1456	-.0017	.1456	-.66	16.7346	-179.34
.110	.1394	-.0015	.1394	-.63	17.1167	-179.37
.105	.1331	-.0014	.1331	-.60	17.5170	-179.40
.100	.1268	-.0013	.1268	-.58	17.9371	-179.42
.095	.1205	-.0011	.1205	-.55	18.3792	-179.45
.090	.1142	-.0010	.1142	-.52	18.8456	-179.48
.085	.1079	-.0009	.1079	-.49	19.3389	-179.51
.080	.1016	-.0008	.1016	-.46	19.8626	-179.54
.075	.0953	-.0007	.0953	-.43	20.4204	-179.57
.070	.0889	-.0006	.0889	-.40	21.0171	-179.60
.065	.0826	-.0005	.0826	-.37	21.658[illegible]	-179.63
.060	.0763	-.0005	.0763	-.34	22.3515	-179.66
.055	.0699	-.0004	.0699	-.32	23.1052	-179.68
.050	.0636	-.0003	.0636	-.29	23.9312	-179.71
.045	.0572	-.0003	.0572	-.26	24.8447	-179.74
.040	.0509	-.0002	.0509	-.23	25.8662	-179.77
.035	.0445	-.0002	.0445	-.20	27.0248	-179.80
.030	.0382	-.0001	.0382	-.17	28.3626	-179.83
.025	.0318	-.0001	.0318	-.14	29.9452	-179.86
.020	.0255	-.0001	.0255	-.11	31.8826	-179.89
.015	.0191	-.0000	.0191	-.09	34.3808	-179.91
.010	.0127	-.0000	.0127	-.06	37.9022	-179.94
.005	.0064	-.0000	.0064	-.03	43.9225	-179.97

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                    RELAY WITH HYSTERESIS AND DEAD ZONE

                                A/B =1.0

     R        REAL       IMAG         GD        PHASE    1/GD(DB)     ANGLE

   1.000     .0000      .0000       .0000        .00   106.6009   -180.00
    .995     .1265     -.0000       .1265       -.00    17.9559   -180.00
    .990     .1778     -.0000       .1778       -.00    15.0004   -180.00
    .985     .2164     -.0000       .2164       -.00    13.2944   -180.00
    .980     .2483     -.0000       .2483       -.00    12.1002   -180.00
    .975     .2759     -.0000       .2759       -.00    11.1865   -180.00
    .970     .3002     -.0000       .3002       -.00    10.4504   -180.00
    .965     .3222     -.0000       .3222       -.00     9.8368   -180.00
    .960     .3423     -.0000       .3423       -.00     9.3131   -180.00
    .955     .3607     -.0000       .3607       -.00     8.8581   -180.00
    .950     .3777     -.0000       .3777       -.00     8.4572   -180.00
    .945     .3935     -.0000       .3935       -.00     8.1003   -180.00
    .940     .4083     -.0000       .4083       -.00     7.7796   -180.00
    .935     .4222     -.0000       .4222       -.00     7.4896   -180.00
    .930     .4352     -.0000       .4352       -.00     7.2255   -180.00
    .925     .4475     -.0000       .4475       -.00     6.9840   -180.00
    .920     .4591     -.0000       .4591       -.00     6.7621   -180.00
    .915     .4700     -.0000       .4700       -.00     6.5574   -180.00
    .910     .4804     -.0000       .4804       -.00     6.3682   -180.00
    .905     .4902     -.0000       .4902       -.00     6.1926   -180.00
    .900     .4995     -.0000       .4995       -.00     6.0294   -180.00
    .895     .5083     -.0000       .5083       -.00     5.8773   -180.00
    .890     .5167     -.0000       .5167       -.00     5.7354   -180.00
    .885     .5246     -.0000       .5246       -.00     5.6028   -180.00
    .880     .5322     -.0000       .5322       -.00     5.4787   -180.00
    .875     .5394     -.0000       .5394       -.00     5.3625   -180.00
    .870     .5462     -.0000       .5462       -.00     5.2535   -180.00
    .865     .5526     -.0000       .5526       -.00     5.1513   -180.00
    .860     .5588     -.0000       .5588       -.00     5.0554   -180.00
    .855     .5646     -.0000       .5646       -.00     4.9653   -180.00
    .850     .5701     -.0000       .5701       -.00     4.8808   -180.00
    .845     .5754     -.0000       .5754       -.00     4.8014   -180.00
    .840     .5803     -.0000       .5803       -.00     4.7268   -180.00
    .835     .5850     -.0000       .5850       -.00     4.6568   -180.00
    .830     .5894     -.0000       .5894       -.00     4.5912   -180.00
    .825     .5936     -.0000       .5936       -.00     4.5297   -180.00
    .820     .5976     -.0000       .5976       -.00     4.4721   -180.00
    .815     .6013     -.0000       .6013       -.00     4.4181   -180.00
    .810     .6048     -.0000       .6048       -.00     4.3678   -180.00
    .805     .6081     -.0000       .6081       -.00     4.3207   -180.00
    .800     .6112     -.0000       .6112       -.00     4.2770   -180.00
    .795     .6140     -.0000       .6140       -.00     4.2363   -180.00
    .790     .6167     -.0000       .6167       -.00     4.1985   -180.00
    .785     .6192     -.0000       .6192       -.00     4.1636   -180.00
    .780     .6215     -.0000       .6215       -.00     4.1315   -180.00
    .775     .6236     -.0000       .6236       -.00     4.1019   -180.00
    .770     .6255     -.0000       .6255       -.00     4.0750   -180.00
    .765     .6273     -.0000       .6273       -.00     4.0504   -180.00
    .760     .6289     -.0000       .6289       -.00     4.0283   -180.00
    .755     .6303     -.0000       .6303       -.00     4.0084   -180.00
```

RELAY WITH HYSTERESIS AND DEAD ZONE

A/B =1.0

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.750	.6316	-.0000	.6316	-.00	3.9908	-180.00
.745	.6328	-.0000	.6328	-.00	3.9753	-180.00
.740	.6337	-.0000	.6337	-.00	3.9619	-180.00
.735	.6346	-.0000	.6346	-.00	3.9506	-180.00
.730	.6352	-.0000	.6352	-.00	3.9412	-180.00
.725	.6358	-.0000	.6358	-.00	3.9338	-180.00
.720	.6362	-.0000	.6362	-.00	3.9283	-180.00
.715	.6365	-.0000	.6365	-.00	3.9246	-180.00
.710	.6366	-.0000	.6366	-.00	3.9227	-180.00
.705	.6366	-.0000	.6366	-.00	3.9225	-180.00
.700	.6365	-.0000	.6365	-.00	3.9241	-180.00
.695	.6363	-.0000	.6363	-.00	3.9274	-180.00
.690	.6359	-.0000	.6359	-.00	3.9323	-180.00
.685	.6354	-.0000	.6354	-.00	3.9389	-180.00
.680	.6348	-.0000	.6348	-.00	3.9470	-180.00
.675	.6341	-.0000	.6341	-.00	3.9567	-180.00
.670	.6333	-.0000	.6333	-.00	3.9680	-180.00
.665	.6324	-.0000	.6324	-.00	3.9808	-180.00
.660	.6313	-.0000	.6313	-.00	3.9950	-180.00
.655	.6302	-.0000	.6302	-.00	4.0108	-180.00
.650	.6289	-.0000	.6289	-.00	4.0280	-180.00
.645	.6276	-.0000	.6276	-.00	4.0467	-180.00
.640	.6261	-.0000	.6261	-.00	4.0667	-180.00
.635	.6246	-.0000	.6246	-.00	4.0882	-180.00
.630	.6229	-.0000	.6229	-.00	4.1111	-180.00
.625	.6212	-.0000	.6212	-.00	4.1353	-180.00
.620	.6194	-.0000	.6194	-.00	4.1610	-180.00
.615	.6175	-.0000	.6175	-.00	4.1880	-180.00
.610	.6154	-.0000	.6154	-.00	4.2163	-180.00
.605	.6133	-.0000	.6133	-.00	4.2460	-180.00
.600	.6112	-.0000	.6112	-.00	4.2770	-180.00
.595	.6089	-.0000	.6089	-.00	4.3093	-180.00
.590	.6065	-.0000	.6065	-.00	4.3429	-180.00
.585	.6041	-.0000	.6041	-.00	4.3779	-180.00
.580	.6016	-.0000	.6016	-.00	4.4142	-180.00
.575	.5990	-.0000	.5990	-.00	4.4517	-180.00
.570	.5963	-.0000	.5963	-.00	4.4906	-180.00
.565	.5936	-.0000	.5936	-.00	4.5308	-180.00
.560	.5907	-.0000	.5907	-.00	4.5723	-180.00
.555	.5878	-.0000	.5878	-.00	4.6150	-180.00
.550	.5849	-.0000	.5849	-.00	4.6591	-180.00
.545	.5818	-.0000	.5818	-.00	4.7045	-180.00
.540	.5787	-.0000	.5787	-.00	4.7511	-180.00
.535	.5755	-.0000	.5755	-.00	4.7991	-180.00
.530	.5722	-.0000	.5722	-.00	4.8484	-180.00
.525	.5689	-.0000	.5689	-.00	4.8990	-180.00
.520	.5655	-.0000	.5655	-.00	4.9509	-180.00
.515	.5621	-.0000	.5621	-.00	5.0041	-180.00
.510	.5586	-.0000	.5586	-.00	5.0587	-180.00
.505	.5550	-.0000	.5550	-.00	5.1146	-180.00

```
                    RELAY WITH HYSTERESIS AND DEAD ZONE

                                A/B =1.0

  R        REAL       IMAG        GD        PHASE    1/GD(DB)    ANGLE

 .500     .5513     -.0000      .5513      -.00      5.1718    -180.00
 .495     .5476     -.0000      .5476      -.00      5.2304    -180.00
 .490     .5439     -.0000      .5439      -.00      5.2903    -180.00
 .485     .5400     -.0000      .5400      -.00      5.3516    -180.00
 .480     .5361     -.0000      .5361      -.00      5.4143    -180.00
 .475     .5322     -.0000      .5322      -.00      5.4784    -180.00
 .470     .5282     -.0000      .5282      -.00      5.5439    -180.00
 .465     .5242     -.0000      .5242      -.00      5.6108    -180.00
 .460     .5200     -.0000      .5200      -.00      5.6792    -180.00
 .455     .5159     -.0000      .5159      -.00      5.7490    -180.00
 .450     .5117     -.0000      .5117      -.00      5.8202    -180.00
 .445     .5074     -.0000      .5074      -.00      5.8930    -180.00
 .440     .5031     -.0000      .5031      -.00      5.9672    -180.00
 .435     .4987     -.0000      .4987      -.00      6.0430    -180.00
 .430     .4943     -.0000      .4943      -.00      6.1203    -180.00
 .425     .4898     -.0000      .4898      -.00      6.1992    -180.00
 .420     .4853     -.0000      .4853      -.00      6.2797    -180.00
 .415     .4807     -.0000      .4807      -.00      6.3617    -180.00
 .410     .4761     -.0000      .4761      -.00      6.4454    -180.00
 .405     .4715     -.0000      .4715      -.00      6.5308    -180.00
 .400     .4668     -.0000      .4668      -.00      6.6178    -180.00
 .395     .4620     -.0000      .4620      -.00      6.7066    -180.00
 .390     .4572     -.0000      .4572      -.00      6.7971    -180.00
 .385     .4524     -.0000      .4524      -.00      6.8893    -180.00
 .380     .4475     -.0000      .4475      -.00      6.9834    -180.00
 .375     .4426     -.0000      .4426      -.00      7.0794    -180.00
 .370     .4377     -.0000      .4377      -.00      7.1772    -180.00
 .365     .4327     -.0000      .4327      -.00      7.2769    -180.00
 .360     .4276     -.0000      .4276      -.00      7.3786    -180.00
 .355     .4226     -.0000      .4226      -.00      7.4822    -180.00
 .350     .4174     -.0000      .4174      -.00      7.5880    -180.00
 .345     .4123     -.0000      .4123      -.00      7.6958    -180.00
 .340     .4071     -.0000      .4071      -.00      7.8057    -180.00
 .335     .4019     -.0000      .4019      -.00      7.9179    -180.00
 .330     .3966     -.0000      .3966      -.00      8.0323    -180.00
 .325     .3913     -.0000      .3913      -.00      8.1489    -180.00
 .320     .3860     -.0000      .3860      -.00      8.2680    -180.00
 .315     .3807     -.0000      .3807      -.00      8.3894    -180.00
 .310     .3753     -.0000      .3753      -.00      8.5134    -180.00
 .305     .3698     -.0000      .3698      -.00      8.6399    -180.00
 .300     .3644     -.0000      .3644      -.00      8.7690    -180.00
 .295     .3589     -.0000      .3589      -.00      8.9008    -180.00
 .290     .3534     -.0000      .3534      -.00      9.0354    -180.00
 .285     .3478     -.0000      .3478      -.00      9.1728    -180.00
 .280     .3422     -.0000      .3422      -.00      9.3132    -180.00
 .275     .3366     -.0000      .3366      -.00      9.4567    -180.00
 .270     .3310     -.0000      .3310      -.00      9.6033    -180.00
 .265     .3253     -.0000      .3253      -.00      9.7531    -180.00
 .260     .3197     -.0000      .3197      -.00      9.9063    -180.00
 .255     .3139     -.0000      .3139      -.00     10.0630    -180.00
```

RELAY WITH HYSTERESIS AND DEAD ZONE

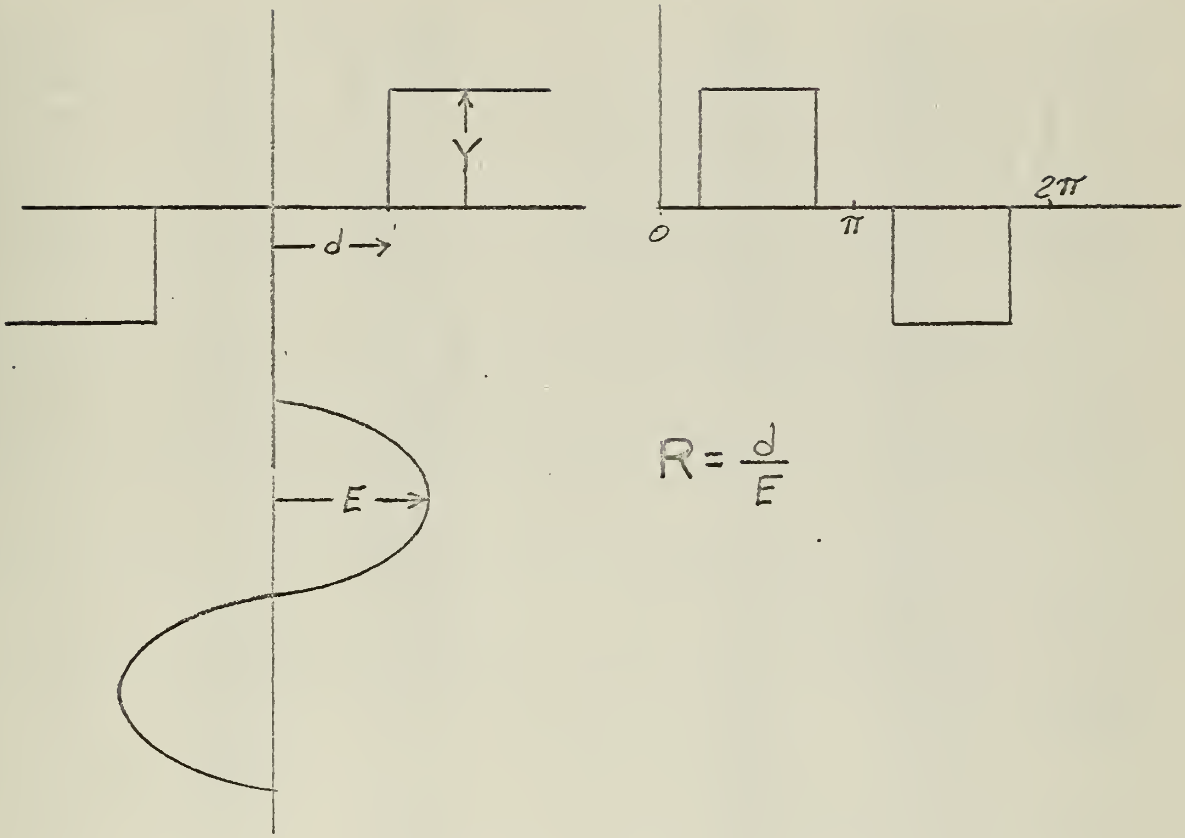
A/B =1.0

R	REAL	IMAG	GD	PHASE	1/GD(DB)	ANGLE
.250	.3082	-.0000	.3082	-.00	10.2233	-180.00
.245	.3024	-.0000	.3024	-.00	10.3873	-180.00
.240	.2966	-.0000	.2966	-.00	10.5552	-180.00
.235	.2908	-.0000	.2908	-.00	10.7272	-180.00
.230	.2850	-.0000	.2850	-.00	10.9033	-180.00
.225	.2791	-.0000	.2791	-.00	11.0838	-180.00
.220	.2732	-.0000	.2732	-.00	11.2688	-180.00
.215	.2673	-.0000	.2673	-.00	11.4586	-180.00
.210	.2614	-.0000	.2614	-.00	11.6533	-180.00
.205	.2555	-.0000	.2555	-.00	11.8532	-180.00
.200	.2495	-.0000	.2495	-.00	12.0585	-180.00
.195	.2435	-.0000	.2435	-.00	12.2695	-180.00
.190	.2375	-.0000	.2375	-.00	12.4864	-180.00
.185	.2315	-.0000	.2315	-.00	12.7096	-180.00
.180	.2254	-.0000	.2254	-.00	12.9394	-180.00
.175	.2194	-.0000	.2194	-.00	13.1761	-180.00
.170	.2133	-.0000	.2133	-.00	13.4202	-180.00
.165	.2072	-.0000	.2072	-.00	13.6720	-180.00
.160	.2011	-.0000	.2011	-.00	13.9320	-180.00
.155	.1950	-.0000	.1950	-.00	14.2008	-180.00
.150	.1888	-.0000	.1888	-.00	14.4788	-180.00
.145	.1827	-.0000	.1827	-.00	14.7667	-180.00
.140	.1765	-.0000	.1765	-.00	15.0652	-180.00
.135	.1703	-.0000	.1703	-.00	15.3750	-180.00
.130	.1641	-.0000	.1641	-.00	15.6970	-180.00
.125	.1579	-.0000	.1579	-.00	16.0320	-180.00
.120	.1517	-.0000	.1517	-.00	16.3812	-180.00
.115	.1455	-.0000	.1455	-.00	16.7457	-180.00
.110	.1392	-.0000	.1392	-.00	17.1268	-180.00
.105	.1330	-.0000	.1330	-.00	17.5262	-180.00
.100	.1267	-.0000	.1267	-.00	17.9455	-180.00
.095	.1204	-.0000	.1204	-.00	18.3867	-180.00
.090	.1141	-.0000	.1141	-.00	18.8523	-180.00
.085	.1078	-.0000	.1078	-.00	19.3449	-180.00
.080	.1015	-.0000	.1015	-.00	19.8679	-180.00
.075	.0952	-.0000	.0952	-.00	20.4251	-180.00
.070	.0889	-.0000	.0889	-.00	21.0212	-180.00
.065	.0826	-.0000	.0826	-.00	21.6619	-180.00
.060	.0763	-.0000	.0763	-.00	22.3545	-180.00
.055	.0699	-.0000	.0699	-.00	23.1077	-180.00
.050	.0636	-.0000	.0636	-.00	23.9333	-180.00
.045	.0572	-.0000	.0572	-.00	24.8464	-180.00
.040	.0509	-.0000	.0509	-.00	25.8676	-180.00
.035	.0445	-.0000	.0445	-.00	27.0258	-180.00
.030	.0382	-.0000	.0382	-.00	28.3633	-180.00
.025	.0318	-.0000	.0318	-.00	29.9457	-180.00
.020	.0255	-.0000	.0255	-.00	31.8830	-180.00
.015	.0191	-.0000	.0191	-.00	34.3810	-180.00
.010	.0127	-.0000	.0127	-.00	37.9023	-180.00
.005	.0064	-.0000	.0064	-.00	43.9225	-180.00

APPENDIX VI

Relay With Deadzone

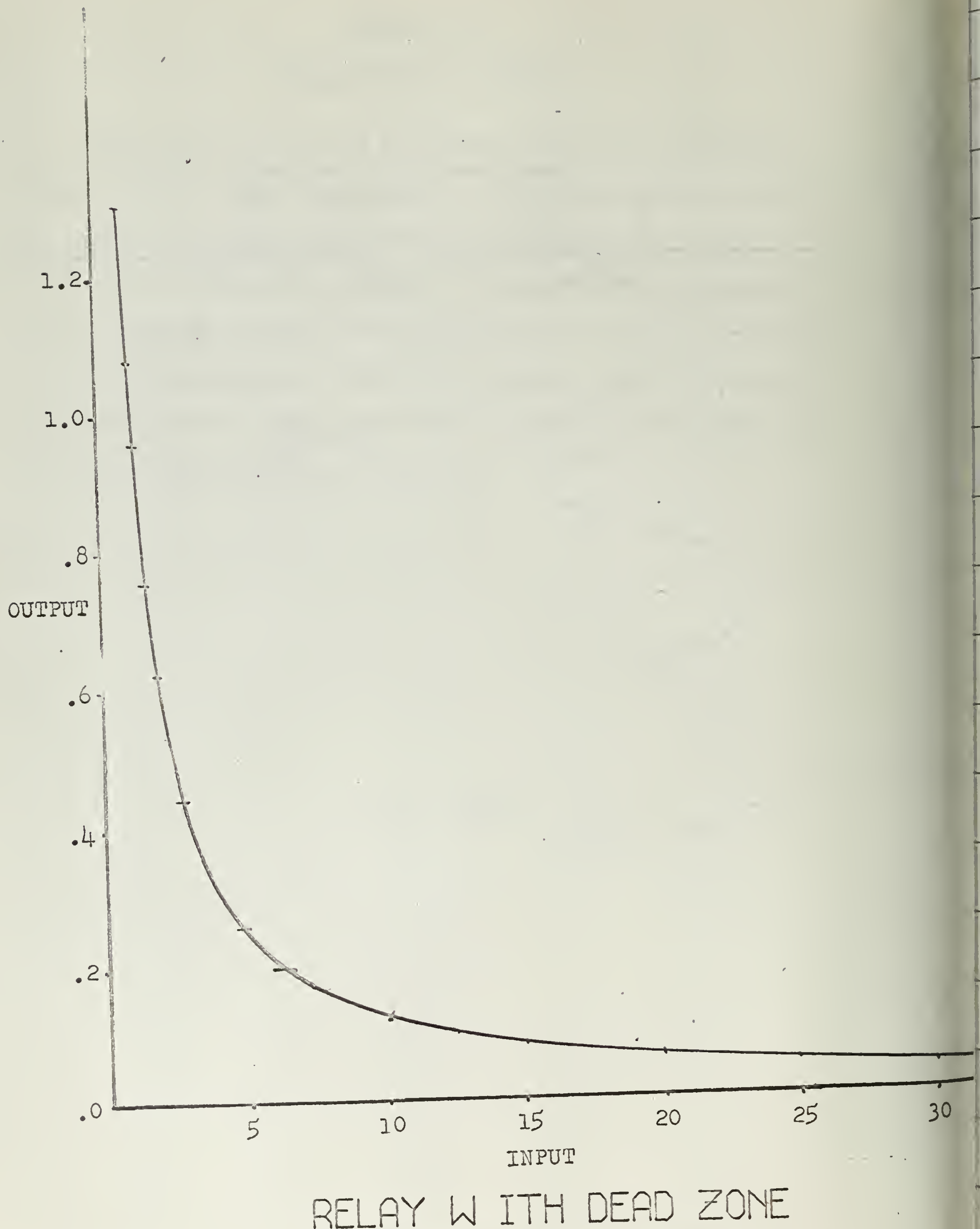
This nonlinear device is commonly used to stabilize systems having small variations. A possible use is in the main error channel of a control system where it is desired to control error with short bursts. When the error increases above a specified value the controller is turned on by the relay and the error is reduced to a value within tolerence. The controller is then turned off and remains off until the error once again exceeds tolerance.



$$R = \frac{d}{E}$$

$$G_D(j\omega) = \frac{4Y}{\pi E}\sqrt{1-R^2}\ \angle 0^\circ$$

Figure VI-1
Relay With Deadzone



RELAY W ITH DEAD ZONE

FIRST HARMONIC OF OUTPUT VS INPUT

Figure VI-2

RELAY WITH DEAD ZONE (NO HYSTERESIS)

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.000	.0000	-6153.0531	.900	.4995	6.0294
.998	.0803	21.9029	.898	.5031	5.9673
.996	.1133	18.9144	.896	.5066	5.9069
.994	.1384	17.1753	.894	.5100	5.8482
.992	.1594	15.9478	.892	.5134	5.7910
.990	.1778	15.0006	.890	.5167	5.7354
.988	.1943	14.2307	.888	.5199	5.6813
.986	.2093	13.5832	.886	.5231	5.6287
.984	.2232	13.0253	.884	.5262	5.5774
.982	.2362	12.5358	.882	.5292	5.5274
.980	.2483	12.1003	.880	.5322	5.4787
.978	.2598	11.7085	.878	.5351	5.4313
.976	.2706	11.3528	.876	.5379	5.3852
.974	.2810	11.0274	.874	.5407	5.3402
.972	.2908	10.7278	.872	.5435	5.2963
.970	.3002	10.4505	.870	.5462	5.2536
.968	.3093	10.1925	.868	.5488	5.2119
.966	.3180	9.9516	.866	.5514	5.1713
.964	.3264	9.7258	.864	.5539	5.1317
.962	.3344	9.5135	.862	.5563	5.0931
.960	.3422	9.3132	.860	.5588	5.0554
.958	.3498	9.1239	.858	.5611	5.0187
.956	.3571	8.9444	.856	.5634	4.9829
.954	.3642	8.7740	.854	.5657	4.9480
.952	.3710	8.6118	.852	.5679	4.9140
.950	.3777	8.4573	.850	.5701	4.8808
.948	.3842	8.3097	.848	.5722	4.8484
.946	.3905	8.1686	.846	.5743	4.8169
.944	.3966	8.0335	.844	.5764	4.7861
.942	.4025	7.9040	.842	.5784	4.7561
.940	.4083	7.7797	.840	.5803	4.7268
.938	.4140	7.6603	.838	.5822	4.6983
.936	.4195	7.5454	.836	.5841	4.6705
.934	.4249	7.4348	.834	.5859	4.6434
.932	.4301	7.3283	.832	.5877	4.6170
.930	.4352	7.2256	.830	.5894	4.5912
.928	.4402	7.1264	.828	.5911	4.5661
.926	.4451	7.0307	.826	.5928	4.5417
.924	.4499	6.9382	.824	.5944	4.5179
.922	.4545	6.8487	.822	.5960	4.4947
.920	.4591	6.7621	.820	.5976	4.4721
.918	.4635	6.6783	.818	.5991	4.4501
.916	.4679	6.5971	.816	.6006	4.4287
.914	.4721	6.5185	.814	.6020	4.4078
.912	.4763	6.4422	.812	.6034	4.3875
.910	.4804	6.3682	.810	.6048	4.3678
.908	.4844	6.2964	.808	.6061	4.3486
.906	.4883	6.2267	.806	.6074	4.3299
.904	.4921	6.1590	.804	.6087	4.3117
.902	.4958	6.0933	.802	.6100	4.2941

RELAY WITH DEAD ZONE (NO HYSTERESIS)

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.800	.6112	4.2770	.700	.6365	3.9241
.798	.6123	4.2603	.698	.6364	3.9252
.796	.6135	4.2442	.696	.6363	3.9266
.794	.6146	4.2285	.694	.6362	3.9283
.792	.6157	4.2133	.692	.6361	3.9302
.790	.6167	4.1985	.690	.6359	3.9323
.788	.6177	4.1842	.688	.6357	3.9348
.786	.6187	4.1704	.686	.6355	3.9374
.784	.6197	4.1570	.684	.6353	3.9404
.782	.6206	4.1440	.682	.6351	3.9436
.780	.6215	4.1315	.680	.6348	3.9470
.778	.6223	4.1194	.678	.6345	3.9507
.776	.6232	4.1076	.676	.6343	3.9547
.774	.6240	4.0964	.674	.6340	3.9589
.772	.6248	4.0855	.672	.6336	3.9633
.770	.6255	4.0750	.670	.6333	3.9680
.768	.6263	4.0649	.668	.6329	3.9729
.766	.6270	4.0551	.666	.6326	3.9781
.764	.6276	4.0458	.664	.6322	3.9835
.762	.6283	4.0369	.662	.6317	3.9892
.760	.6289	4.0283	.660	.6313	3.9950
.758	.6295	4.0201	.658	.6309	4.0012
.756	.6301	4.0122	.656	.6304	4.0075
.754	.6306	4.0047	.654	.6299	4.0141
.752	.6311	3.9976	.652	.6294	4.0209
.750	.6316	3.9908	.650	.6289	4.0280
.748	.6321	3.9843	.648	.6284	4.0353
.746	.6325	3.9782	.646	.6279	4.0428
.744	.6330	3.9725	.644	.6273	4.0506
.742	.6334	3.9670	.642	.6267	4.0585
.740	.6337	3.9619	.640	.6261	4.0667
.738	.6341	3.9572	.638	.6255	4.0752
.736	.6344	3.9527	.636	.6249	4.0838
.734	.6347	3.9486	.634	.6243	4.0927
.732	.6350	3.9447	.632	.6236	4.1018
.730	.6352	3.9412	.630	.6229	4.1111
.728	.6355	3.9380	.628	.6223	4.1206
.726	.6357	3.9351	.626	.6216	4.1304
.724	.6359	3.9326	.624	.6208	4.1404
.722	.6360	3.9303	.622	.6201	4.1506
.720	.6362	3.9283	.620	.6194	4.1610
.718	.6363	3.9266	.618	.6186	4.1716
.716	.6364	3.9252	.616	.6178	4.1825
.714	.6365	3.9241	.614	.6171	4.1935
.712	.6366	3.9232	.612	.6163	4.2048
.710	.6366	3.9227	.610	.6154	4.2163
.708	.6366	3.9224	.608	.6146	4.2280
.706	.6366	3.9224	.606	.6138	4.2399
.704	.6366	3.9227	.604	.6129	4.2521
.702	.6366	3.9233	.602	.6120	4.2644

RELAY WITH DEAD ZONE (NO HYSTERESIS)

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.600	.6112	4.2770	.500	.5513	5.1718
.598	.6103	4.2897	.498	.5499	5.1950
.596	.6093	4.3027	.496	.5484	5.2185
.594	.6084	4.3159	.494	.5469	5.2422
.592	.6075	4.3293	.492	.5454	5.2662
.590	.6065	4.3429	.490	.5439	5.2903
.588	.6056	4.3568	.488	.5423	5.3147
.586	.6046	4.3708	.486	.5408	5.3392
.584	.6036	4.3850	.484	.5393	5.3640
.582	.6026	4.3995	.482	.5377	5.3891
.580	.6016	4.4142	.480	.5361	5.4143
.578	.6005	4.4290	.478	.5346	5.4398
.576	.5995	4.4441	.476	.5330	5.4655
.574	.5985	4.4594	.474	.5314	5.4914
.572	.5974	4.4749	.472	.5298	5.5175
.570	.5963	4.4906	.470	.5282	5.5439
.568	.5952	4.5065	.468	.5266	5.5705
.566	.5941	4.5226	.466	.5250	5.5973
.564	.5930	4.5390	.464	.5233	5.6244
.562	.5919	4.5555	.462	.5217	5.6517
.560	.5907	4.5723	.460	.5200	5.6792
.558	.5896	4.5892	.458	.5184	5.7069
.556	.5884	4.6064	.456	.5167	5.7349
.554	.5872	4.6237	.454	.5150	5.7631
.552	.5860	4.6413	.452	.5134	5.7915
.550	.5849	4.6591	.450	.5117	5.8202
.548	.5836	4.6771	.448	.5100	5.8492
.546	.5824	4.6953	.446	.5083	5.8783
.544	.5812	4.7137	.444	.5065	5.9077
.542	.5799	4.7323	.442	.5048	5.9374
.540	.5787	4.7511	.440	.5031	5.9672
.538	.5774	4.7702	.438	.5013	5.9974
.536	.5761	4.7894	.436	.4996	6.0277
.534	.5749	4.8089	.434	.4978	6.0583
.532	.5736	4.8285	.432	.4961	6.0892
.530	.5722	4.8484	.430	.4943	6.1203
.528	.5709	4.8685	.428	.4925	6.1517
.526	.5696	4.8887	.426	.4907	6.1833
.524	.5682	4.9092	.424	.4889	6.2151
.522	.5669	4.9300	.422	.4871	6.2473
.520	.5655	4.9509	.420	.4853	6.2796
.518	.5642	4.9720	.418	.4835	6.3123
.516	.5628	4.9934	.416	.4817	6.3452
.514	.5614	5.0149	.414	.4798	6.3783
.512	.5600	5.0367	.412	.4780	6.4117
.510	.5586	5.0587	.410	.4761	6.4454
.508	.5571	5.0809	.408	.4743	6.4793
.506	.5557	5.1033	.406	.4724	6.5136
.504	.5543	5.1259	.404	.4705	6.5480
.502	.5528	5.1487	.402	.4687	6.5828

RELAY WITH DEAD ZONE (NO HYSTERESIS)

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.400	.4668	6.6178	.300	.3644	8.7690
.398	.4649	6.6531	.298	.3622	8.8213
.396	.4630	6.6887	.296	.3600	8.8742
.394	.4611	6.7245	.294	.3578	8.9275
.392	.4592	6.7606	.292	.3556	8.9812
.390	.4572	6.7971	.290	.3534	9.0353
.388	.4553	6.8337	.288	.3512	9.0900
.386	.4534	6.8707	.286	.3489	9.1451
.384	.4514	6.9080	.284	.3467	9.2006
.382	.4495	6.9456	.282	.3445	9.2567
.380	.4475	6.9834	.280	.3422	9.3132
.378	.4456	7.0216	.278	.3400	9.3702
.376	.4436	7.0600	.276	.3378	9.4277
.374	.4416	7.0987	.274	.3355	9.4857
.372	.4397	7.1378	.272	.3333	9.5442
.370	.4377	7.1771	.270	.3310	9.6032
.368	.4357	7.2168	.268	.3287	9.6628
.366	.4337	7.2568	.266	.3265	9.7229
.364	.4317	7.2970	.264	.3242	9.7835
.362	.4297	7.3376	.262	.3219	9.8446
.360	.4276	7.3786	.260	.3197	9.9063
.358	.4256	7.4198	.258	.3174	9.9686
.356	.4236	7.4613	.256	.3151	10.0314
.354	.4215	7.5032	.254	.3128	10.0948
.352	.4195	7.5454	.252	.3105	10.1587
.350	.4174	7.5880	.250	.3082	10.2233
.348	.4154	7.6308	.248	.3059	10.2884
.346	.4133	7.6740	.246	.3036	10.3542
.344	.4113	7.7176	.244	.3013	10.4206
.342	.4092	7.7615	.242	.2990	10.4876
.340	.4071	7.8057	.240	.2966	10.5552
.338	.4050	7.8503	.238	.2943	10.6235
.336	.4029	7.8953	.236	.2920	10.6924
.334	.4008	7.9406	.234	.2897	10.7620
.332	.3987	7.9862	.232	.2873	10.8323
.330	.3966	8.0322	.230	.2850	10.9033
.328	.3945	8.0786	.228	.2827	10.9749
.326	.3924	8.1254	.226	.2803	11.0473
.324	.3903	8.1725	.224	.2780	11.1204
.322	.3881	8.2201	.222	.2756	11.1942
.320	.3860	8.2680	.220	.2733	11.2688
.318	.3839	8.3163	.218	.2709	11.3441
.316	.3817	8.3649	.216	.2685	11.4202
.314	.3796	8.4140	.214	.2662	11.4971
.312	.3774	8.4635	.212	.2638	11.5748
.310	.3753	8.5134	.210	.2614	11.6533
.308	.3731	8.5636	.208	.2590	11.7326
.306	.3709	8.6143	.206	.2567	11.8128
.304	.3687	8.6655	.204	.2543	11.8938
.302	.3666	8.7170	.202	.2519	11.9757

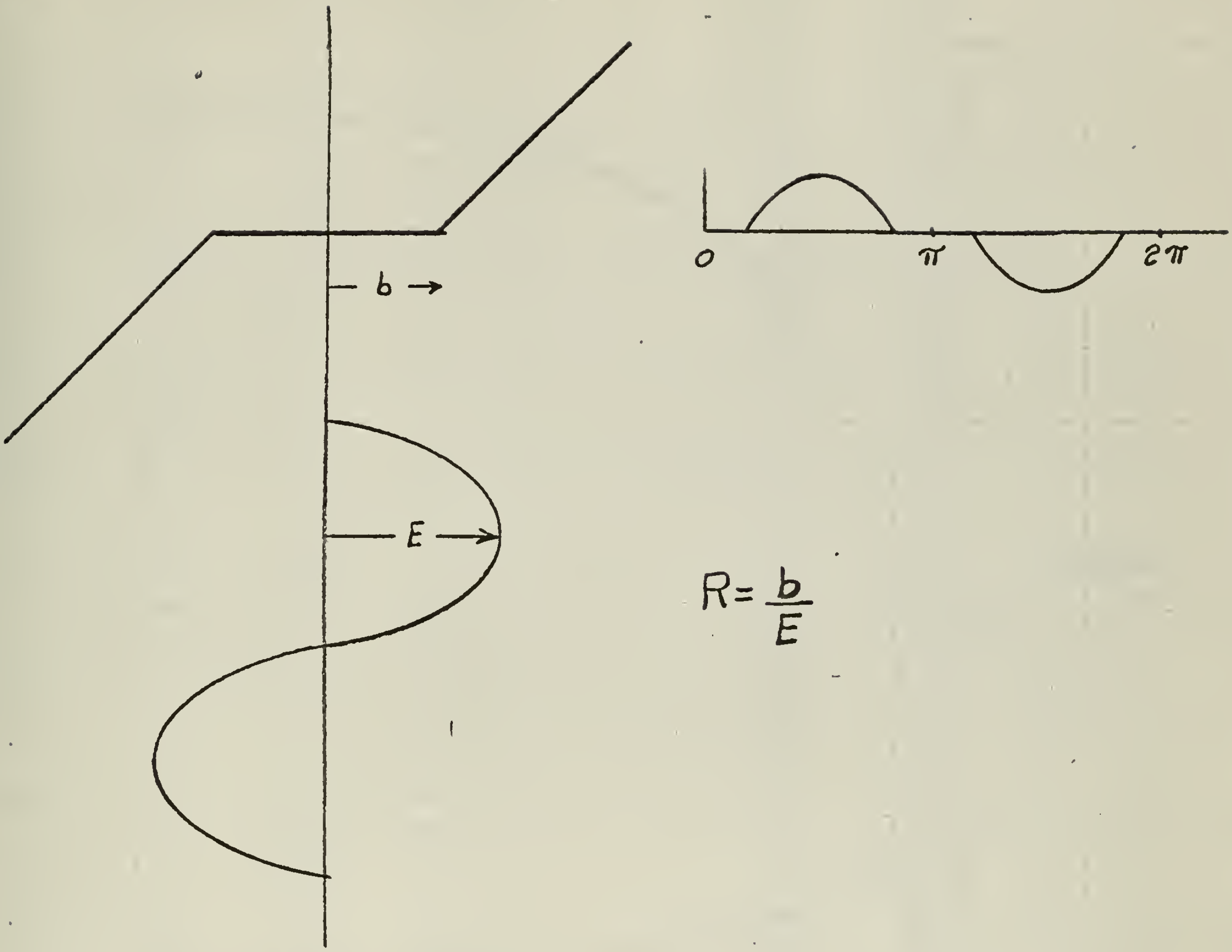
RELAY WITH DEAD ZONE (NO HYSTERESIS)

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.200	.2495	12.0585	.100	.1267	17.9454
.198	.2471	12.1422	.098	.1242	18.1192
.196	.2447	12.2268	.096	.1217	18.2966
.194	.2423	12.3124	.094	.1192	18.4778
.192	.2399	12.3989	.092	.1166	18.6629
.190	.2375	12.4864	.090	.1141	18.8523
.188	.2351	12.5749	.088	.1116	19.0459
.186	.2327	12.6644	.086	.1091	19.2441
.184	.2303	12.7550	.084	.1066	19.4470
.182	.2279	12.8467	.082	.1041	19.6548
.180	.2254	12.9394	.080	.1015	19.8679
.178	.2230	13.0332	.078	.0990	20.0864
.176	.2206	13.1282	.076	.0965	20.3107
.174	.2182	13.2243	.074	.0940	20.5410
.172	.2157	13.3216	.072	.0914	20.7777
.170	.2133	13.4202	.070	.0889	21.0212
.168	.2109	13.5199	.068	.0864	21.2717
.166	.2084	13.6210	.066	.0839	21.5299
.164	.2060	13.7233	.064	.0813	21.7960
.162	.2035	13.8270	.062	.0788	22.0707
.160	.2011	13.9320	.060	.0763	22.3544
.158	.1986	14.0384	.058	.0737	22.6479
.156	.1962	14.1463	.056	.0712	22.9517
.154	.1937	14.2556	.054	.0687	23.2666
.152	.1913	14.3664	.052	.0661	23.5935
.150	.1888	14.4788	.050	.0636	23.9333
.148	.1864	14.5927	.048	.0610	24.2870
.146	.1839	14.7083	.046	.0585	24.6558
.144	.1814	14.8255	.044	.0560	25.0412
.142	.1790	14.9445	.042	.0534	25.4445
.140	.1765	15.0652	.040	.0509	25.8675
.138	.1740	15.1877	.038	.0483	26.3124
.136	.1716	15.3121	.036	.0458	26.7814
.134	.1691	15.4384	.034	.0433	27.2772
.132	.1666	15.5667	.032	.0407	27.8032
.130	.1641	15.6969	.030	.0382	28.3633
.128	.1616	15.8293	.028	.0356	28.9620
.126	.1591	15.9639	.026	.0331	29.6053
.124	.1567	16.1007	.024	.0305	30.3001
.122	.1542	16.2397	.022	.0280	31.0554
.120	.1517	16.3812	.020	.0255	31.8829
.118	.1492	16.5250	.018	.0229	32.7977
.116	.1467	16.6715	.016	.0204	33.8205
.114	.1442	16.8205	.014	.0178	34.9801
.112	.1417	16.9723	.012	.0153	36.3188
.110	.1392	17.1268	.010	.0127	37.9022
.108	.1367	17.2843	.008	.0102	39.8403
.106	.1342	17.4447	.006	.0076	42.3389
.104	.1317	17.6084	.004	.0051	45.8607
.102	.1292	17.7752	.002	.0025	51.8812

APPENDIX VII

Deadzone

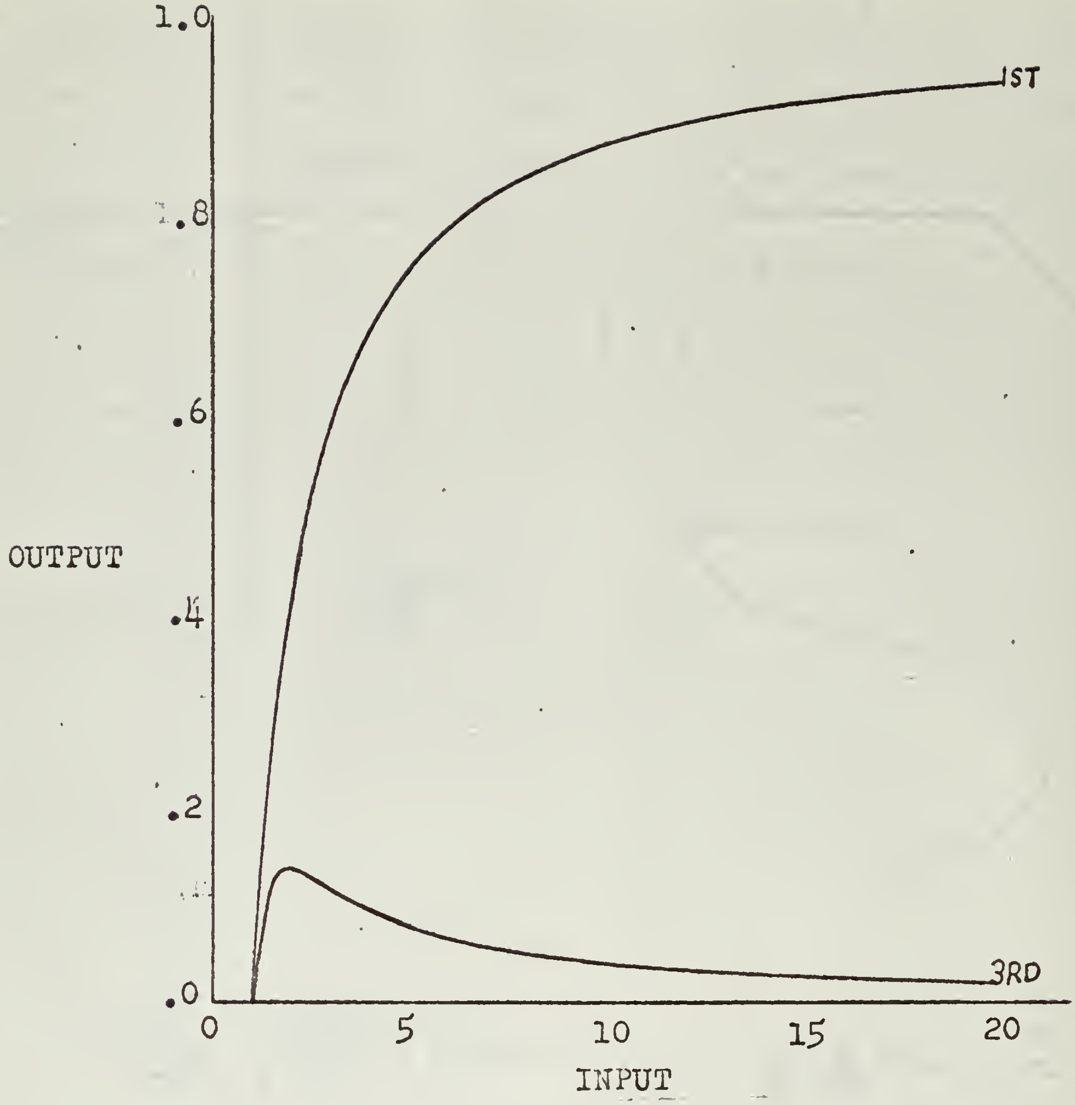
Deadzone is often an inadvertant and undesirable nonlinearity in servosystems. In general it contributes to instability but could be used to reduce or eliminate small oscillations in error signals.



$$R=\frac{b}{E}$$

$$G_D(j\omega)=\frac{2}{\pi}\left(\frac{\pi}{2}-\sin^{-1}R-R\sqrt{1-R^2}\right)\angle 0^\circ$$

Figure VII-1 Dead Zone



FIRST AND THIRD HARMONICS VS INPUT
Figure VII-2

DEADZONE

DEADZONE

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	.0000	*	.9000	.0374	28.5460
.9980	.0001	79.4536	.8980	.0385	28.2907
.9960	.0003	70.3809	.8960	.0396	28.0404
.9940	.0006	65.0898	.8940	.0408	27.7949
.9920	.0009	61.3396	.8920	.0419	27.5541
.9900	.0012	58.4325	.8900	.0431	27.3177
.9880	.0016	56.0582	.8880	.0442	27.0856
.9860	.0020	54.0515	.8860	.0454	26.8577
.9840	.0024	52.3136	.8840	.0466	26.6338
.9820	.0029	50.7812	.8820	.0478	26.4138
.9800	.0034	49.4107	.8800	.0490	26.1975
.9780	.0039	48.1713	.8780	.0502	25.9849
.9760	.0044	47.0400	.8760	.0514	25.7758
.9740	.0050	45.9996	.8740	.0527	25.5700
.9720	.0056	45.0365	.8720	.0539	25.3675
.9700	.0062	44.1401	.8700	.0552	25.1683
.9680	.0068	43.3018	.8680	.0564	24.9721
.9660	.0075	42.5145	.8660	.0577	24.7789
.9640	.0082	41.7723	.8640	.0590	24.5886
.9620	.0088	41.0705	.8620	.0602	24.4011
.9600	.0095	40.4047	.8600	.0615	24.2163
.9580	.0103	39.7717	.8580	.0628	24.0343
.9560	.0110	39.1681	.8560	.0642	23.8548
.9540	.0118	38.5916	.8540	.0655	23.6778
.9520	.0125	38.0397	.8520	.0668	23.5033
.9500	.0133	37.5105	.8500	.0681	23.3311
.9480	.0141	37.0021	.8480	.0695	23.1613
.9460	.0149	36.5130	.8460	.0708	22.9937
.9440	.0158	36.0418	.8440	.0722	22.8283
.9420	.0166	35.5872	.8420	.0736	22.6651
.9400	.0175	35.1482	.8400	.0750	22.5040
.9380	.0184	34.7236	.8380	.0763	22.3449
.9360	.0192	34.3126	.8360	.0777	22.1878
.9340	.0202	33.9143	.8340	.0791	22.0326
.9320	.0211	33.5280	.8320	.0805	21.8793
.9300	.0220	33.1530	.8300	.0820	21.7279
.9280	.0229	32.7886	.8280	.0834	21.5782
.9260	.0239	32.4343	.8260	.0848	21.4304
.9240	.0249	32.0895	.8240	.0863	21.2842
.9220	.0258	31.7537	.8220	.0877	21.1398
.9200	.0268	31.4265	.8200	.0892	20.9970
.9180	.0278	31.1075	.8180	.0906	20.8558
.9160	.0289	30.7962	.8160	.0921	20.7162
.9140	.0299	30.4923	.8140	.0936	20.5781
.9120	.0309	30.1954	.8120	.0950	20.4415
.9100	.0320	29.9053	.8100	.0965	20.3064
.9080	.0330	29.6216	.8080	.0980	20.1728
.9060	.0341	29.3441	.8060	.0995	20.0405
.9040	.0352	29.0725	.8040	.1010	19.9097
.9020	.0363	28.8065	.8020	.1026	19.7802

DEADZONE

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.1041	19.6520	.7000	.1881	14.5113
.7980	.1056	19.5252	.6980	.1899	14.4276
.7960	.1072	19.3996	.6960	.1918	14.3445
.7940	.1087	19.2753	.6940	.1936	14.2620
.7920	.1103	19.1522	.6920	.1954	14.1800
.7900	.1118	19.0303	.6900	.1973	14.0986
.7880	.1134	18.9096	.6880	.1991	14.0177
.7860	.1149	18.7901	.6860	.2010	13.9374
.7840	.1165	18.6717	.6840	.2028	13.8575
.7820	.1181	18.5544	.6820	.2047	13.7783
.7800	.1197	18.4383	.6800	.2066	13.6995
.7780	.1213	18.3232	.6780	.2084	13.6212
.7760	.1229	18.2091	.6760	.2103	13.5435
.7740	.1245	18.0961	.6740	.2122	13.4662
.7720	.1261	17.9841	.6720	.2141	13.3894
.7700	.1277	17.8732	.6700	.2159	13.3132
.7680	.1294	17.7632	.6680	.2178	13.2374
.7660	.1310	17.6542	.6660	.2197	13.1620
.7640	.1326	17.5461	.6640	.2216	13.0872
.7620	.1343	17.4390	.6620	.2235	13.0128
.7600	.1359	17.3328	.6600	.2255	12.9389
.7580	.1376	17.2275	.6580	.2274	12.8654
.7560	.1393	17.1231	.6560	.2293	12.7924
.7540	.1409	17.0196	.6540	.2312	12.7198
.7520	.1426	16.9169	.6520	.2331	12.6476
.7500	.1443	16.8151	.6500	.2351	12.5759
.7480	.1460	16.7141	.6480	.2370	12.5046
.7460	.1477	16.6140	.6460	.2390	12.4337
.7440	.1494	16.5146	.6440	.2409	12.3633
.7420	.1511	16.4161	.6420	.2428	12.2933
.7400	.1528	16.3183	.6400	.2448	12.2236
.7380	.1545	16.2213	.6380	.2468	12.1544
.7360	.1562	16.1251	.6360	.2487	12.0856
.7340	.1579	16.0296	.6340	.2507	12.0172
.7320	.1597	15.9349	.6320	.2527	11.9491
.7300	.1614	15.8409	.6300	.2546	11.8815
.7280	.1632	15.7476	.6280	.2566	11.8142
.7260	.1649	15.6550	.6260	.2586	11.7473
.7240	.1667	15.5631	.6240	.2606	11.6808
.7220	.1684	15.4719	.6220	.2626	11.6147
.7200	.1702	15.3814	.6200	.2646	11.5489
.7180	.1720	15.2915	.6180	.2666	11.4835
.7160	.1737	15.2023	.6160	.2686	11.4184
.7140	.1755	15.1138	.6140	.2706	11.3537
.7120	.1773	15.0259	.6120	.2726	11.2894
.7100	.1791	14.9386	.6100	.2746	11.2254
.7080	.1809	14.8519	.6080	.2766	11.1618
.7060	.1827	14.7659	.6060	.2787	11.0984
.7040	.1845	14.6804	.6040	.2807	11.0355
.7020	.1863	14.5956	.6020	.2827	10.9728

DEADZONE

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.2848	10.9105	.5000	.3910	8.1564
.5980	.2868	10.8486	.4980	.3932	8.1075
.5960	.2888	10.7869	.4960	.3954	8.0589
.5940	.2909	10.7256	.4940	.3976	8.0104
.5920	.2929	10.6646	.4920	.3998	7.9621
.5900	.2950	10.6039	.4900	.4021	7.9141
.5880	.2970	10.5435	.4880	.4043	7.8662
.5860	.2991	10.4834	.4860	.4065	7.8186
.5840	.3012	10.4236	.4840	.4087	7.7711
.5820	.3032	10.3642	.4820	.4110	7.7239
.5800	.3053	10.3050	.4800	.4132	7.6768
.5780	.3074	10.2461	.4780	.4154	7.6299
.5760	.3095	10.1876	.4760	.4177	7.5833
.5740	.3116	10.1293	.4740	.4199	7.5368
.5720	.3136	10.0713	.4720	.4222	7.4905
.5700	.3157	10.0136	.4700	.4244	7.4444
.5680	.3178	9.9562	.4680	.4267	7.3985
.5660	.3199	9.8990	.4660	.4289	7.3528
.5640	.3220	9.8422	.4640	.4312	7.3073
.5620	.3241	9.7856	.4620	.4334	7.2619
.5600	.3262	9.7293	.4600	.4357	7.2167
.5580	.3283	9.6733	.4580	.4379	7.1717
.5560	.3305	9.6175	.4560	.4402	7.1269
.5540	.3326	9.5620	.4540	.4425	7.0823
.5520	.3347	9.5068	.4520	.4447	7.0379
.5500	.3368	9.4518	.4500	.4470	6.9936
.5480	.3390	9.3971	.4480	.4493	6.9495
.5460	.3411	9.3426	.4460	.4516	6.9056
.5440	.3432	9.2884	.4440	.4538	6.8618
.5420	.3454	9.2345	.4420	.4561	6.8182
.5400	.3475	9.1808	.4400	.4584	6.7748
.5380	.3496	9.1273	.4380	.4607	6.7316
.5360	.3518	9.0741	.4360	.4630	6.6885
.5340	.3539	9.0212	.4340	.4653	6.6456
.5320	.3561	8.9685	.4320	.4676	6.6028
.5300	.3583	8.9160	.4300	.4699	6.5603
.5280	.3604	8.8638	.4280	.4722	6.5178
.5260	.3626	8.8118	.4260	.4745	6.4756
.5240	.3648	8.7600	.4240	.4768	6.4335
.5220	.3669	8.7085	.4220	.4791	6.3916
.5200	.3691	8.6572	.4200	.4814	6.3498
.5180	.3713	8.6061	.4180	.4837	6.3082
.5160	.3735	8.5552	.4160	.4860	6.2667
.5140	.3756	8.5046	.4140	.4883	6.2254
.5120	.3778	8.4542	.4120	.4907	6.1842
.5100	.3800	8.4040	.4100	.4930	6.1432
.5080	.3822	8.3541	.4080	.4953	6.1024
.5060	.3844	8.3044	.4060	.4976	6.0617
.5040	.3866	8.2548	.4040	.5000	6.0212
.5020	.3888	8.2055	.4020	.5023	5.9808

DEADZONE

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.5046	5.9405	.3000	.6238	4.0986
.3980	.5070	5.9004	.2980	.6263	4.0648
.3960	.5093	5.8605	.2960	.6287	4.0311
.3940	.5116	5.8207	.2940	.6311	3.9976
.3920	.5140	5.7810	.2920	.6336	3.9642
.3900	.5163	5.7415	.2900	.6360	3.9308
.3880	.5187	5.7021	.2880	.6384	3.8976
.3860	.5210	5.6629	.2860	.6409	3.8645
.3840	.5234	5.6238	.2840	.6433	3.8314
.3820	.5257	5.5848	.2820	.6458	3.7985
.3800	.5281	5.5460	.2800	.6482	3.7657
.3780	.5304	5.5073	.2780	.6507	3.7330
.3760	.5328	5.4688	.2760	.6531	3.7004
.3740	.5352	5.4304	.2740	.6555	3.6679
.3720	.5375	5.3921	.2720	.6580	3.6355
.3700	.5399	5.3540	.2700	.6604	3.6032
.3680	.5422	5.3160	.2680	.6629	3.5710
.3660	.5446	5.2782	.2660	.6654	3.5389
.3640	.5470	5.2404	.2640	.6678	3.5069
.3620	.5494	5.2028	.2620	.6703	3.4750
.3600	.5517	5.1654	.2600	.6727	3.4432
.3580	.5541	5.1280	.2580	.6752	3.4115
.3560	.5565	5.0908	.2560	.6776	3.3799
.3540	.5589	5.0538	.2540	.6801	3.3484
.3520	.5613	5.0168	.2520	.6826	3.3170
.3500	.5636	4.9800	.2500	.6850	3.2857
.3480	.5660	4.9433	.2480	.6875	3.2545
.3460	.5684	4.9067	.2460	.6900	3.2234
.3440	.5708	4.8703	.2440	.6924	3.1924
.3420	.5732	4.8339	.2420	.6949	3.1614
.3400	.5756	4.7977	.2400	.6974	3.1306
.3380	.5780	4.7617	.2380	.6999	3.0998
.3360	.5804	4.7257	.2360	.7023	3.0692
.3340	.5828	4.6899	.2340	.7048	3.0386
.3320	.5852	4.6542	.2320	.7073	3.0082
.3300	.5876	4.6186	.2300	.7098	2.9778
.3280	.5900	4.5831	.2280	.7122	2.9475
.3260	.5924	4.5477	.2260	.7147	2.9173
.3240	.5948	4.5125	.2240	.7172	2.8872
.3220	.5972	4.4774	.2220	.7197	2.8572
.3200	.5996	4.4424	.2200	.7222	2.8273
.3180	.6020	4.4075	.2180	.7246	2.7975
.3160	.6045	4.3727	.2160	.7271	2.7677
.3140	.6069	4.3380	.2140	.7296	2.7381
.3120	.6093	4.3035	.2120	.7321	2.7085
.3100	.6117	4.2691	.2100	.7346	2.6790
.3080	.6141	4.2347	.2080	.7371	2.6496
.3060	.6166	4.2005	.2060	.7396	2.6203
.3040	.6190	4.1664	.2040	.7421	2.5911
.3020	.6214	4.1324	.2020	.7446	2.5619

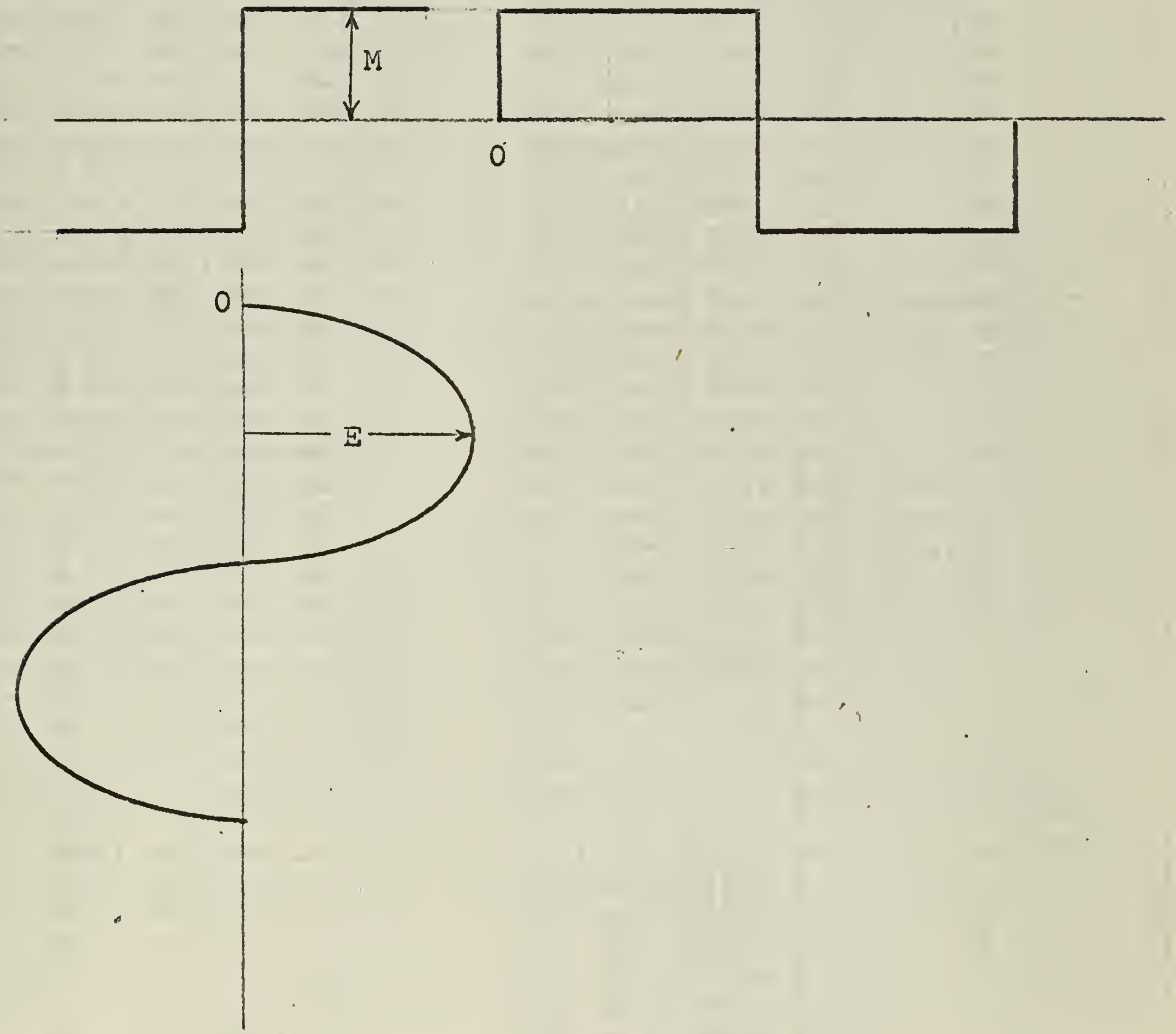
DEADZONE

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.2000	.7471	2.5329	.1000	.8729	1.1808
.1980	.7496	2.5039	.0980	.8754	1.1556
.1960	.7521	2.4750	.0960	.8780	1.1305
.1940	.7545	2.4462	.0940	.8805	1.1055
.1920	.7570	2.4175	.0920	.8830	1.0805
.1900	.7595	2.3889	.0900	.8856	1.0556
.1880	.7620	2.3603	.0880	.8881	1.0308
.1860	.7645	2.3319	.0860	.8906	1.0060
.1840	.7671	2.3035	.0840	.8932	.9813
.1820	.7696	2.2752	.0820	.8957	.9566
.1800	.7721	2.2470	.0800	.8982	.9321
.1780	.7746	2.2188	.0780	.9008	.9075
.1760	.7771	2.1908	.0760	.9033	.8831
.1740	.7796	2.1628	.0740	.9059	.8587
.1720	.7821	2.1349	.0720	.9084	.8344
.1700	.7846	2.1071	.0700	.9109	.8101
.1680	.7871	2.0793	.0680	.9135	.7860
.1660	.7896	2.0517	.0660	.9160	.7618
.1640	.7921	2.0241	.0640	.9186	.7378
.1620	.7946	1.9966	.0620	.9211	.7138
.1600	.7972	1.9692	.0600	.9237	.6898
.1580	.7997	1.9418	.0580	.9262	.6660
.1560	.8022	1.9145	.0560	.9287	.6422
.1540	.8047	1.8873	.0540	.9313	.6184
.1520	.8072	1.8602	.0520	.9338	.5947
.1500	.8097	1.8332	.0500	.9364	.5711
.1480	.8123	1.8062	.0480	.9389	.5475
.1460	.8148	1.7793	.0460	.9415	.5240
.1440	.8173	1.7525	.0440	.9440	.5006
.1420	.8198	1.7257	.0420	.9465	.4772
.1400	.8223	1.6991	.0400	.9491	.4539
.1380	.8249	1.6725	.0380	.9516	.4307
.1360	.8274	1.6460	.0360	.9542	.4075
.1340	.8299	1.6195	.0340	.9567	.3843
.1320	.8324	1.5931	.0320	.9593	.3612
.1300	.8349	1.5668	.0300	.9618	.3382
.1280	.8375	1.5406	.0280	.9644	.3153
.1260	.8400	1.5144	.0260	.9669	.2924
.1240	.8425	1.4884	.0240	.9694	.2695
.1220	.8451	1.4623	.0220	.9720	.2468
.1200	.8476	1.4364	.0200	.9745	.2240
.1180	.8501	1.4105	.0180	.9771	.2014
.1160	.8526	1.3847	.0160	.9796	.1788
.1140	.8552	1.3590	.0140	.9822	.1562
.1120	.8577	1.3333	.0120	.9847	.1337
.1100	.8602	1.3077	.0100	.9873	.1113
.1080	.8628	1.2822	.0080	.9898	.0889
.1060	.8653	1.2568	.0060	.9924	.0666
.1040	.8678	1.2314	.0040	.9949	.0443
.1020	.8704	1.2061	.0020	.9975	.0221

APPENDIX VIII

Ideal Relay

The characteristics of the ideal relay are very nearly achieved by electronic devices which have approximately zero dead time. It is a very useful device in systems where instantaneous switching is required. It may be symmetrical as shown in Figure VIII-1 or may be biased to switch between two levels of positive or negative output.



$GD = \frac{4M}{\pi E}$ ZERO PHASE SHIFT

$= \frac{4RM}{\pi}$ $R = \frac{1}{E}$

IDEAL RELAY
Figure VIII-1

IDEAL RELAY

R	GD	1/GD(DB)	R	GD	1/GD(DB)
100.000	127.3241	-42.0982	50.000	63.6620	-36.0776
99.000	126.0508	-42.0109	49.000	62.3888	-35.9021
98.000	124.7776	-41.9227	48.000	61.1155	-35.7230
97.000	123.5043	-41.8336	47.000	59.8423	-35.5402
96.000	122.2311	-41.7436	46.000	58.5691	-35.3534
95.000	120.9579	-41.6527	45.000	57.2958	-35.1625
94.000	119.6846	-41.5608	44.000	56.0226	-34.9673
93.000	118.4114	-41.4679	43.000	54.7493	-34.7676
92.000	117.1381	-41.3740	42.000	53.4761	-34.5632
91.000	115.8649	-41.2790	41.000	52.2029	-34.3539
90.000	114.5917	-41.1831	40.000	50.9296	-34.1394
89.000	113.3184	-41.0860	39.000	49.6564	-33.9195
88.000	112.0452	-40.9879	38.000	48.3831	-33.6939
87.000	110.7719	-40.8886	37.000	47.1099	-33.4622
86.000	109.4987	-40.7882	36.000	45.8367	-33.2243
85.000	108.2255	-40.6866	35.000	44.5634	-32.9796
84.000	106.9522	-40.5838	34.000	43.2902	-32.7278
83.000	105.6790	-40.4798	33.000	42.0169	-32.4685
82.000	104.4057	-40.3745	32.000	40.7437	-32.2012
81.000	103.1325	-40.2679	31.000	39.4705	-31.9254
80.000	101.8592	-40.1600	30.000	38.1972	-31.6406
79.000	100.5860	-40.0508	29.000	36.9240	-31.3462
78.000	99.3128	-39.9401	28.000	35.6507	-31.0414
77.000	98.0395	-39.8280	27.000	34.3775	-30.7255
76.000	96.7663	-39.7145	26.000	33.1043	-30.3977
75.000	95.4930	-39.5994	25.000	31.8310	-30.0570
74.000	94.2198	-39.4828	24.000	30.5578	-29.7024
73.000	92.9466	-39.3647	23.000	29.2845	-29.3328
72.000	91.6733	-39.2449	22.000	28.0113	-28.9467
71.000	90.4001	-39.1234	21.000	26.7381	-28.5426
70.000	89.1268	-39.0002	20.000	25.4648	-28.1188
69.000	87.8536	-38.8752	19.000	24.1916	-27.6733
68.000	86.5804	-38.7484	18.000	22.9183	-27.2037
67.000	85.3071	-38.6197	17.000	21.6451	-26.7072
66.000	84.0339	-38.4891	16.000	20.3718	-26.1806
65.000	82.7606	-38.3565	15.000	19.0986	-25.6200
64.000	81.4874	-38.2218	14.000	17.8254	-25.0208
63.000	80.2142	-38.0850	13.000	16.5521	-24.3771
62.000	78.9409	-37.9460	12.000	15.2789	-23.6818
61.000	77.6677	-37.8048	11.000	14.0056	-22.9261
60.000	76.3944	-37.6612	10.000	12.7324	-22.0982
59.000	75.1212	-37.5152	9.000	11.4592	-21.1831
58.000	73.8480	-37.3668	8.000	10.1859	-20.1600
57.000	72.5747	-37.2157	7.000	8.9127	-19.0002
56.000	71.3015	-37.0620	6.000	7.6394	-17.6612
55.000	70.0282	-36.9055	5.000	6.3662	-16.0776
54.000	68.7550	-36.7461	4.000	5.0930	-14.1394
53.000	67.4818	-36.5837	3.000	3.8197	-11.6406
52.000	66.2085	-36.4183	2.000	2.5465	-8.1188
51.000	64.9353	-36.2496	1.000	1.2732	-2.0982

IDEAL RELAY

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.998	1.2707	-2.0808	.898	1.1434	-1.1637
.996	1.2681	-2.0634	.896	1.1408	-1.1444
.994	1.2656	-2.0459	.894	1.1383	-1.1250
.992	1.2631	-2.0284	.892	1.1357	-1.1055
.990	1.2605	-2.0109	.890	1.1332	-1.0860
.988	1.2580	-1.9933	.888	1.1306	-1.0665
.986	1.2554	-1.9757	.886	1.1281	-1.0469
.984	1.2529	-1.9581	.884	1.1255	-1.0273
.982	1.2503	-1.9404	.882	1.1230	-1.0076
.980	1.2478	-1.9227	.880	1.1205	-.9879
.978	1.2452	-1.9050	.878	1.1179	-.9681
.976	1.2427	-1.8872	.876	1.1154	-.9483
.974	1.2401	-1.8694	.874	1.1128	-.9284
.972	1.2376	-1.8515	.872	1.1103	-.9085
.970	1.2350	-1.8336	.870	1.1077	-.8886
.968	1.2325	-1.8157	.868	1.1052	-.8686
.966	1.2300	-1.7978	.866	1.1026	-.8486
.964	1.2274	-1.7798	.864	1.1001	-.8285
.962	1.2249	-1.7617	.862	1.0975	-.8084
.960	1.2223	-1.7436	.860	1.0950	-.7882
.958	1.2198	-1.7255	.858	1.0924	-.7680
.956	1.2172	-1.7074	.856	1.0899	-.7477
.954	1.2147	-1.6892	.854	1.0873	-.7274
.952	1.2121	-1.6709	.852	1.0848	-.7070
.950	1.2096	-1.6527	.850	1.0823	-.6866
.948	1.2070	-1.6344	.848	1.0797	-.6661
.946	1.2045	-1.6160	.846	1.0772	-.6456
.944	1.2019	-1.5976	.844	1.0746	-.6251
.942	1.1994	-1.5792	.842	1.0721	-.6045
.940	1.1968	-1.5608	.840	1.0695	-.5838
.938	1.1943	-1.5423	.838	1.0670	-.5631
.936	1.1918	-1.5237	.836	1.0644	-.5423
.934	1.1892	-1.5051	.834	1.0619	-.5215
.932	1.1867	-1.4865	.832	1.0593	-.5007
.930	1.1841	-1.4679	.830	1.0568	-.4798
.928	1.1816	-1.4492	.828	1.0542	-.4588
.926	1.1790	-1.4304	.826	1.0517	-.4378
.924	1.1765	-1.4116	.824	1.0492	-.4168
.922	1.1739	-1.3928	.822	1.0466	-.3956
.920	1.1714	-1.3740	.820	1.0441	-.3745
.918	1.1688	-1.3551	.818	1.0415	-.3533
.916	1.1663	-1.3361	.816	1.0390	-.3320
.914	1.1637	-1.3171	.814	1.0364	-.3107
.912	1.1612	-1.2981	.812	1.0339	-.2893
.910	1.1586	-1.2790	.810	1.0313	-.2679
.908	1.1561	-1.2599	.808	1.0288	-.2464
.906	1.1536	-1.2408	.806	1.0262	-.2249
.904	1.1510	-1.2216	.804	1.0237	-.2033
.902	1.1485	-1.2023	.802	1.0211	-.1817
.900	1.1459	-1.1831	.800	1.0186	-.1600

IDEAL RELAY

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.798	1.0160	-.1383	.698	.8887	1.0247
.796	1.0135	-.1165	.696	.8862	1.0496
.794	1.0110	-.0946	.694	.8836	1.0746
.792	1.0084	-.0727	.692	.8811	1.0997
.790	1.0059	-.0508	.690	.8785	1.1248
.788	1.0033	-.0287	.688	.8760	1.1500
.786	1.0008	-.0067	.686	.8734	1.1753
.784	.9982	.0155	.684	.8709	1.2007
.782	.9957	.0377	.682	.8684	1.2261
.780	.9931	.0599	.680	.8658	1.2516
.778	.9906	.0822	.678	.8633	1.2772
.776	.9880	.1046	.676	.8607	1.3029
.774	.9855	.1270	.674	.8582	1.3286
.772	.9829	.1494	.672	.8556	1.3544
.770	.9804	.1720	.670	.8531	1.3803
.768	.9778	.1946	.668	.8505	1.4063
.766	.9753	.2172	.666	.8480	1.4323
.764	.9728	.2399	.664	.8454	1.4584
.762	.9702	.2627	.662	.8429	1.4846
.760	.9677	.2855	.660	.8403	1.5109
.758	.9651	.3084	.658	.8378	1.5373
.756	.9626	.3314	.656	.8352	1.5637
.754	.9600	.3544	.654	.8327	1.5902
.752	.9575	.3774	.652	.8302	1.6168
.750	.9549	.4006	.650	.8276	1.6435
.748	.9524	.4238	.648	.8251	1.6703
.746	.9498	.4470	.646	.8225	1.6971
.744	.9473	.4703	.644	.8200	1.7241
.742	.9447	.4937	.642	.8174	1.7511
.740	.9422	.5172	.640	.8149	1.7782
.738	.9397	.5407	.638	.8123	1.8054
.736	.9371	.5642	.636	.8098	1.8326
.734	.9346	.5879	.634	.8072	1.8600
.732	.9320	.6116	.632	.8047	1.8874
.730	.9295	.6353	.630	.8021	1.9150
.728	.9269	.6592	.628	.7996	1.9426
.726	.9244	.6831	.626	.7970	1.9703
.724	.9218	.7070	.624	.7945	1.9981
.722	.9193	.7310	.622	.7920	2.0260
.720	.9167	.7551	.620	.7894	2.0540
.718	.9142	.7793	.618	.7869	2.0820
.716	.9116	.8035	.616	.7843	2.1102
.714	.9091	.8278	.614	.7818	2.1384
.712	.9065	.8522	.612	.7792	2.1668
.710	.9040	.8766	.610	.7767	2.1952
.708	.9015	.9011	.608	.7741	2.2237
.706	.8989	.9257	.606	.7716	2.2523
.704	.8964	.9503	.604	.7690	2.2811
.702	.8938	.9750	.602	.7665	2.3099
.700	.8913	.9998	.600	.7639	2.3388

IDEAL RELAY

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.598	.7614	2.3678	.498	.6341	3.9572
.596	.7589	2.3969	.496	.6315	3.9922
.594	.7563	2.4261	.494	.6290	4.0273
.592	.7538	2.4554	.492	.6264	4.0625
.590	.7512	2.4848	.490	.6239	4.0979
.588	.7487	2.5142	.488	.6213	4.1334
.586	.7461	2.5438	.486	.6188	4.1691
.584	.7436	2.5735	.484	.6162	4.2049
.582	.7410	2.6033	.482	.6137	4.2408
.580	.7385	2.6332	.480	.6112	4.2770
.578	.7359	2.6632	.478	.6086	4.3132
.576	.7334	2.6933	.476	.6061	4.3497
.574	.7308	2.7236	.474	.6035	4.3862
.572	.7283	2.7539	.472	.6010	4.4230
.570	.7257	2.7843	.470	.5984	4.4598
.568	.7232	2.8148	.468	.5959	4.4969
.566	.7207	2.8455	.466	.5933	4.5341
.564	.7181	2.8762	.464	.5908	4.5714
.562	.7156	2.9071	.462	.5882	4.6090
.560	.7130	2.9380	.460	.5857	4.6466
.558	.7105	2.9691	.458	.5831	4.6845
.556	.7079	3.0003	.456	.5806	4.7225
.554	.7054	3.0316	.454	.5781	4.7607
.552	.7028	3.0630	.452	.5755	4.7990
.550	.7003	3.0945	.450	.5730	4.8375
.548	.6977	3.1262	.448	.5704	4.8762
.546	.6952	3.1579	.446	.5679	4.9151
.544	.6926	3.1898	.444	.5653	4.9541
.542	.6901	3.2218	.442	.5628	4.9933
.540	.6875	3.2539	.440	.5602	5.0327
.538	.6850	3.2861	.438	.5577	5.0723
.536	.6825	3.3185	.436	.5551	5.1121
.534	.6799	3.3510	.434	.5526	5.1520
.532	.6774	3.3836	.432	.5500	5.1921
.530	.6748	3.4163	.430	.5475	5.2324
.528	.6723	3.4491	.428	.5449	5.2729
.526	.6697	3.4821	.426	.5424	5.3136
.524	.6672	3.5152	.424	.5399	5.3545
.522	.6646	3.5484	.422	.5373	5.3955
.520	.6621	3.5817	.420	.5348	5.4368
.518	.6595	3.6152	.418	.5322	5.4783
.516	.6570	3.6488	.416	.5297	5.5199
.514	.6544	3.6825	.414	.5271	5.5618
.512	.6519	3.7164	.412	.5246	5.6038
.510	.6494	3.7504	.410	.5220	5.6461
.508	.6468	3.7845	.408	.5195	5.6886
.506	.6443	3.8188	.406	.5169	5.7313
.504	.6417	3.8532	.404	.5144	5.7742
.502	.6392	3.8877	.402	.5118	5.8173
.500	.6366	3.9224	.400	.5093	5.8606

IDEAL RELAY

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.398	.5067	5.9041	.298	.3794	8.4175
.396	.5042	5.9479	.296	.3769	8.4760
.394	.5017	5.9919	.294	.3743	8.5348
.392	.4991	6.0361	.292	.3718	8.5941
.390	.4966	6.0805	.290	.3692	8.6538
.388	.4940	6.1252	.288	.3667	8.7139
.386	.4915	6.1700	.286	.3641	8.7745
.384	.4889	6.2152	.284	.3616	8.8354
.382	.4864	6.2605	.282	.3591	8.8968
.380	.4838	6.3061	.280	.3565	8.9586
.378	.4813	6.3520	.278	.3540	9.0209
.376	.4787	6.3980	.276	.3514	9.0836
.374	.4762	6.4444	.274	.3489	9.1468
.372	.4736	6.4909	.272	.3463	9.2104
.370	.4711	6.5378	.270	.3438	9.2745
.368	.4686	6.5848	.268	.3412	9.3391
.366	.4660	6.6322	.266	.3387	9.4042
.364	.4635	6.6798	.264	.3361	9.4697
.362	.4609	6.7276	.262	.3336	9.5358
.360	.4584	6.7757	.260	.3310	9.6023
.358	.4558	6.8241	.258	.3285	9.6694
.356	.4533	6.8728	.256	.3259	9.7370
.354	.4507	6.9217	.254	.3234	9.8051
.352	.4482	6.9709	.252	.3209	9.8738
.350	.4456	7.0204	.250	.3183	9.9430
.348	.4431	7.0702	.248	.3158	10.0128
.346	.4405	7.1203	.246	.3132	10.0831
.344	.4380	7.1706	.244	.3107	10.1540
.342	.4354	7.2213	.242	.3081	10.2255
.340	.4329	7.2722	.240	.3056	10.2976
.338	.4304	7.3235	.238	.3030	10.3703
.336	.4278	7.3750	.236	.3005	10.4436
.334	.4253	7.4269	.234	.2979	10.5175
.332	.4227	7.4790	.232	.2954	10.5920
.330	.4202	7.5315	.230	.2928	10.6672
.328	.4176	7.5843	.228	.2903	10.7431
.326	.4151	7.6374	.226	.2878	10.8196
.324	.4125	7.6909	.224	.2852	10.8968
.322	.4100	7.7447	.222	.2827	10.9747
.320	.4074	7.7988	.220	.2801	11.0533
.318	.4049	7.8532	.218	.2776	11.1327
.316	.4023	7.9080	.216	.2750	11.2127
.314	.3998	7.9632	.214	.2725	11.2935
.312	.3973	8.0187	.212	.2699	11.3751
.310	.3947	8.0746	.210	.2674	11.4574
.308	.3922	8.1308	.208	.2648	11.5405
.306	.3896	8.1874	.206	.2623	11.6244
.304	.3871	8.2443	.204	.2597	11.7092
.302	.3845	8.3017	.202	.2572	11.7948
.300	.3820	8.3594	.200	.2546	11.8812

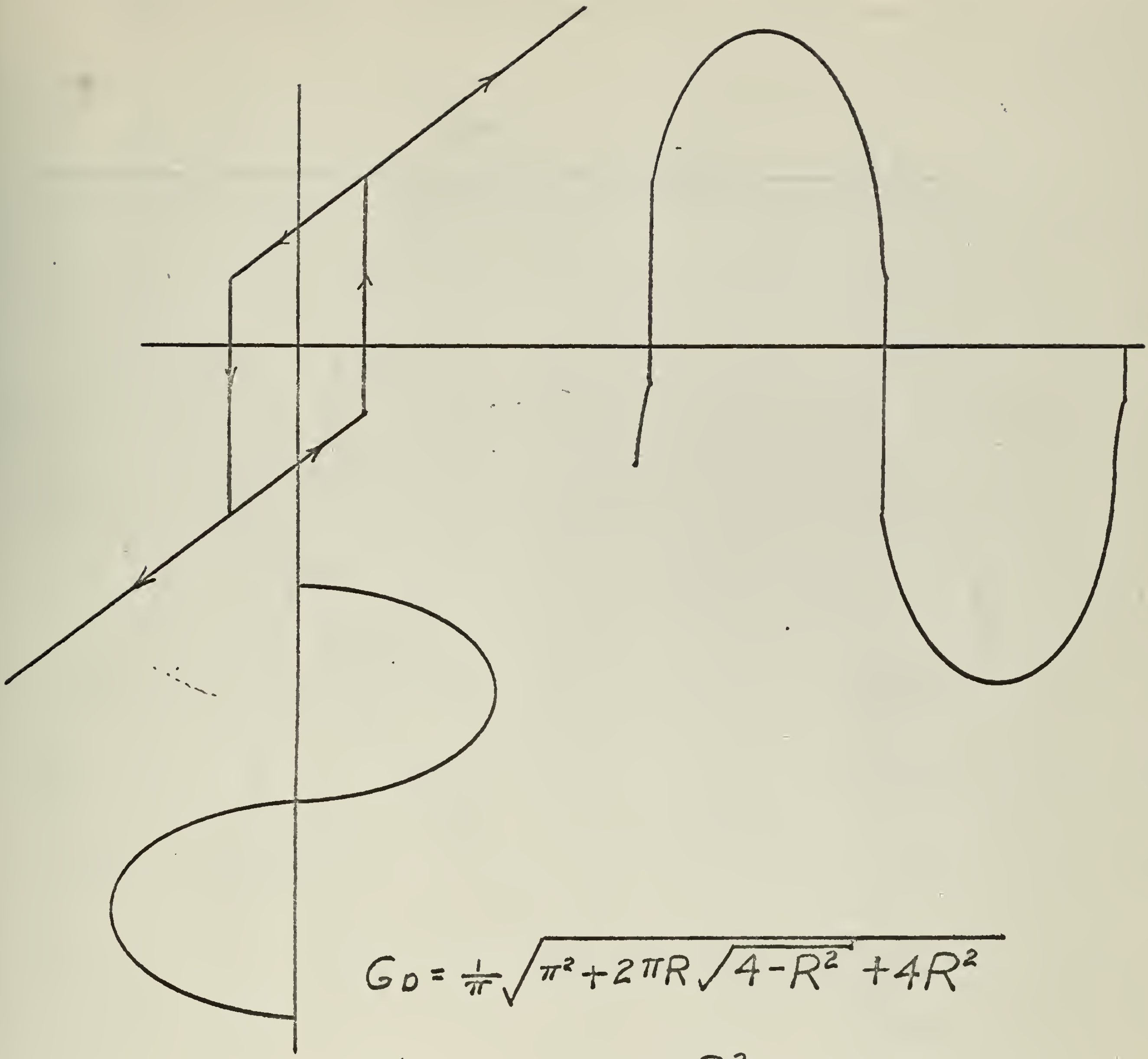
IDEAL RELAY

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.198	.2521	11.9685	.098	.1248	18.0773
.196	.2496	12.0567	.096	.1222	18.2564
.194	.2470	12.1458	.094	.1197	18.4392
.192	.2445	12.2358	.092	.1171	18.6260
.190	.2419	12.3267	.090	.1146	18.8169
.188	.2394	12.4186	.088	.1120	19.0121
.186	.2368	12.5115	.086	.1095	19.2118
.184	.2343	12.6054	.084	.1070	19.4162
.182	.2317	12.7004	.082	.1044	19.6255
.180	.2292	12.7963	.080	.1019	19.8400
.178	.2266	12.8934	.078	.0993	20.0599
.176	.2241	12.9915	.076	.0968	20.2855
.174	.2215	13.0908	.074	.0942	20.5172
.172	.2190	13.1912	.072	.0917	20.7551
.170	.2165	13.2928	.070	.0891	20.9998
.168	.2139	13.3956	.068	.0866	21.2516
.166	.2114	13.4996	.066	.0840	21.5109
.164	.2088	13.6049	.064	.0815	21.7782
.162	.2063	13.7115	.062	.0789	22.0540
.160	.2037	13.8194	.060	.0764	22.3388
.158	.2012	13.9286	.058	.0738	22.6332
.156	.1986	14.0393	.056	.0713	22.9380
.154	.1961	14.1514	.054	.0688	23.2539
.152	.1935	14.2649	.052	.0662	23.5817
.150	.1910	14.3800	.050	.0637	23.9224
.148	.1884	14.4966	.048	.0611	24.2770
.146	.1859	14.6147	.046	.0586	24.6466
.144	.1833	14.7345	.044	.0560	25.0327
.142	.1808	14.8560	.042	.0535	25.4368
.140	.1783	14.9792	.040	.0509	25.8606
.138	.1757	15.1042	.038	.0484	26.3061
.136	.1732	15.2310	.036	.0458	26.7757
.134	.1706	15.3597	.034	.0433	27.2722
.132	.1681	15.4903	.032	.0407	27.7988
.130	.1655	15.6229	.030	.0382	28.3594
.128	.1630	15.7576	.028	.0357	28.9586
.126	.1604	15.8944	.026	.0331	29.6023
.124	.1579	16.0334	.024	.0306	30.2976
.122	.1553	16.1746	.022	.0280	31.0533
.120	.1528	16.3182	.020	.0255	31.8812
.118	.1502	16.4642	.018	.0229	32.7963
.116	.1477	16.6126	.016	.0204	33.8194
.114	.1451	16.7637	.014	.0178	34.9792
.112	.1426	16.9174	.012	.0153	36.3182
.110	.1401	17.0739	.010	.0127	37.9018
.108	.1375	17.2333	.008	.0102	39.8400
.106	.1350	17.3957	.006	.0076	42.3388
.104	.1324	17.5611	.004	.0051	45.8606
.102	.1299	17.7298	.002	.0025	51.8812
.100	.1273	17.9018	.000	.0000	*

APPENDIX IX

Negative Deficiency

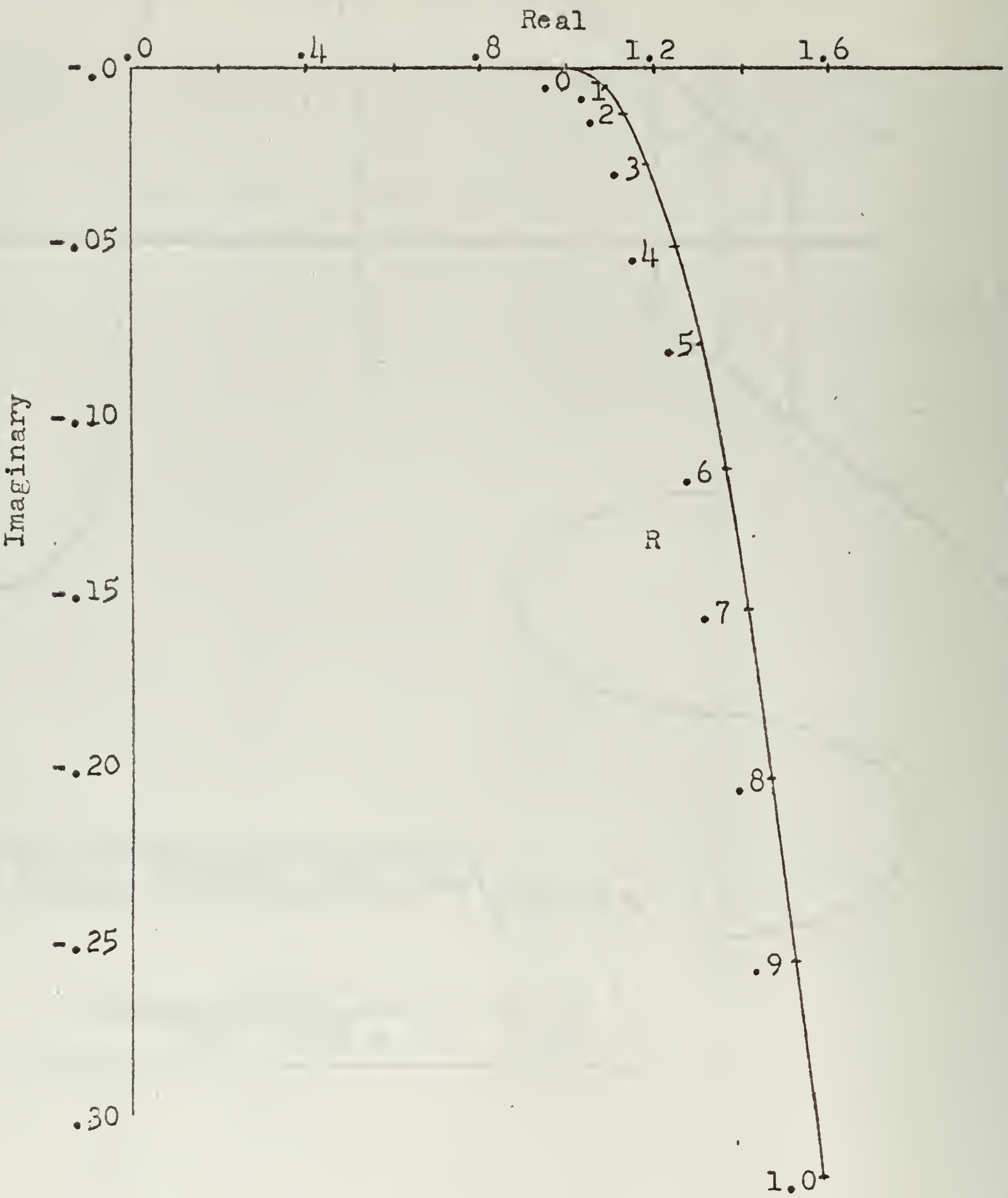
This is a rather uncommon nonlinearity, but frequently the data may be used for other nonlinearities which closely approximate that shown in Fig. IX-1.



$$G_D = \frac{1}{\pi}\sqrt{\pi^2 + 2\pi R\sqrt{4-R^2} + 4R^2}$$

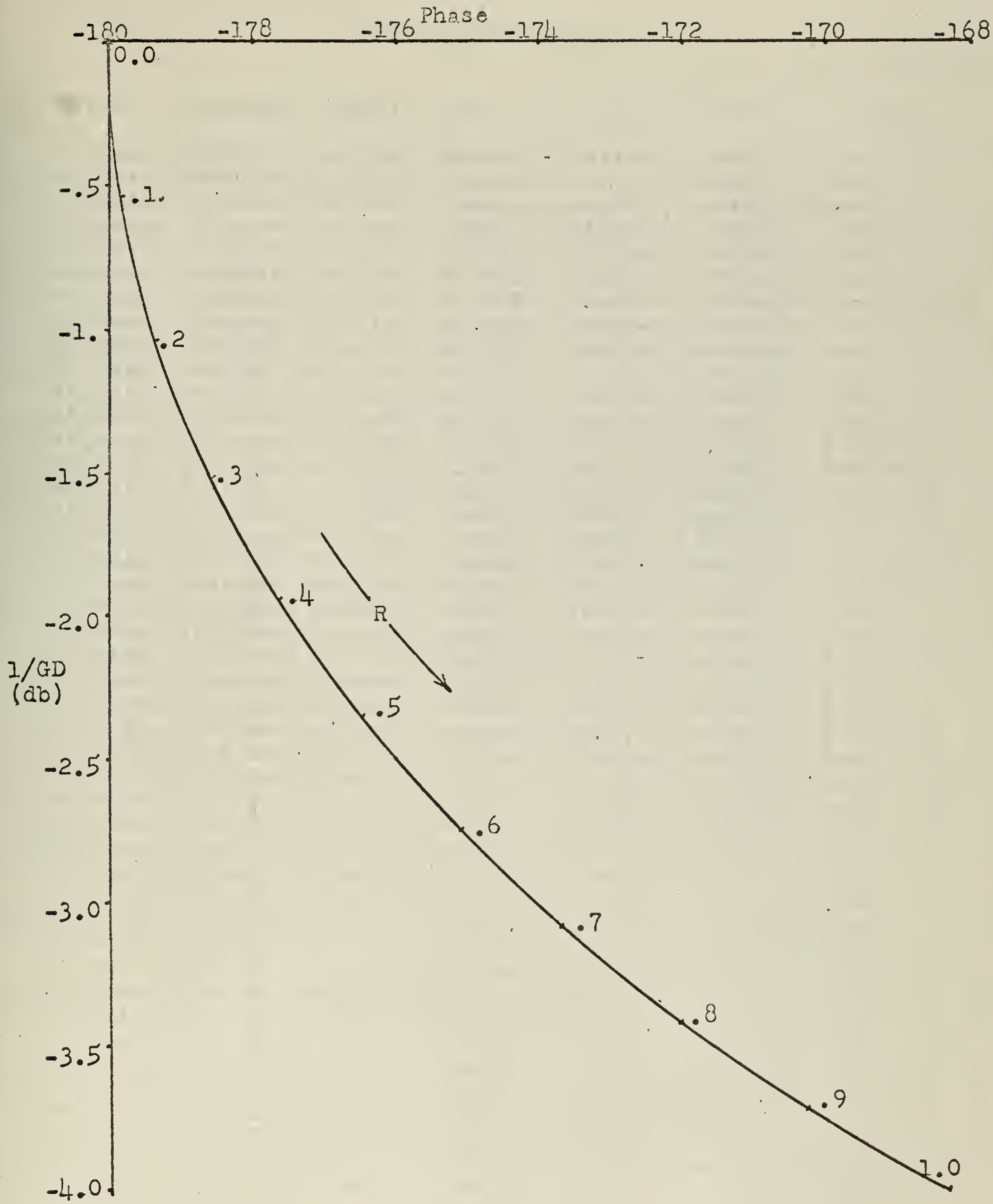
$$\underline{/\ \mathrm{Tan}^{-1}\ \frac{-R^2}{\pi + R\sqrt{4-R^2}}}$$

NEGATIVE DEFICIENCY
Figure IX-1



REAL AND IMAGINARY COMPONENTS

NEGATIVE DEFICIENCY
Figure IX-2



MAGNITUDE (DB) VS PHASE

NEGATIVE DEFICIENCY

Figure IX-3

NEGATIVE DEFICIENCY

R	X	Y	GD	PHASE	1/GD(DB)	THETA
1.000	1.5513	-.3183	1.5836	-11.60	-3.9932	-168.40
.998	1.5506	-.3170	1.5827	-11.56	-3.9878	-168.44
.996	1.5499	-.3158	1.5817	-11.52	-3.9824	-168.48
.994	1.5491	-.3145	1.5807	-11.48	-3.9771	-168.52
.992	1.5484	-.3132	1.5797	-11.44	-3.9717	-168.56
.990	1.5476	-.3120	1.5788	-11.40	-3.9663	-168.60
.988	1.5469	-.3107	1.5778	-11.36	-3.9609	-168.64
.986	1.5461	-.3095	1.5768	-11.32	-3.9555	-168.68
.984	1.5454	-.3082	1.5758	-11.28	-3.9500	-168.72
.982	1.5446	-.3070	1.5748	-11.24	-3.9446	-168.76
.980	1.5439	-.3057	1.5738	-11.20	-3.9392	-168.80
.978	1.5431	-.3045	1.5728	-11.16	-3.9337	-168.84
.976	1.5423	-.3032	1.5719	-11.12	-3.9282	-168.88
.974	1.5416	-.3020	1.5709	-11.08	-3.9228	-168.92
.972	1.5408	-.3007	1.5699	-11.04	-3.9173	-168.96
.970	1.5400	-.2995	1.5689	-11.01	-3.9118	-168.99
.968	1.5393	-.2983	1.5679	-10.97	-3.9063	-169.03
.966	1.5385	-.2970	1.5669	-10.93	-3.9008	-169.07
.964	1.5377	-.2958	1.5659	-10.89	-3.8953	-169.11
.962	1.5369	-.2946	1.5649	-10.85	-3.8897	-169.15
.960	1.5361	-.2934	1.5639	-10.81	-3.8842	-169.19
.958	1.5354	-.2921	1.5629	-10.77	-3.8787	-169.23
.956	1.5346	-.2909	1.5619	-10.73	-3.8731	-169.27
.954	1.5338	-.2897	1.5609	-10.70	-3.8675	-169.30
.952	1.5330	-.2885	1.5599	-10.66	-3.8620	-169.34
.950	1.5322	-.2873	1.5589	-10.62	-3.8564	-169.38
.948	1.5314	-.2861	1.5579	-10.58	-3.8508	-169.42
.946	1.5306	-.2849	1.5569	-10.54	-3.8452	-169.46
.944	1.5298	-.2837	1.5559	-10.50	-3.8396	-169.50
.942	1.5290	-.2825	1.5549	-10.47	-3.8339	-169.53
.940	1.5282	-.2813	1.5539	-10.43	-3.8283	-169.57
.938	1.5274	-.2801	1.5529	-10.39	-3.8227	-169.61
.936	1.5266	-.2789	1.5519	-10.35	-3.8170	-169.65
.934	1.5258	-.2777	1.5508	-10.31	-3.8114	-169.69
.932	1.5250	-.2765	1.5498	-10.28	-3.8057	-169.72
.930	1.5242	-.2753	1.5488	-10.24	-3.8000	-169.76
.928	1.5233	-.2741	1.5478	-10.20	-3.7943	-169.80
.926	1.5225	-.2729	1.5468	-10.16	-3.7886	-169.84
.924	1.5217	-.2718	1.5458	-10.13	-3.7829	-169.87
.922	1.5209	-.2706	1.5448	-10.09	-3.7772	-169.91
.920	1.5200	-.2694	1.5437	-10.05	-3.7715	-169.95
.918	1.5192	-.2682	1.5427	-10.01	-3.7657	-169.99
.916	1.5184	-.2671	1.5417	-9.98	-3.7600	-170.02
.914	1.5176	-.2659	1.5407	-9.94	-3.7542	-170.06
.912	1.5167	-.2648	1.5397	-9.90	-3.7485	-170.10
.910	1.5159	-.2636	1.5386	-9.86	-3.7427	-170.14
.908	1.5150	-.2624	1.5376	-9.83	-3.7369	-170.17
.906	1.5142	-.2613	1.5366	-9.79	-3.7311	-170.21
.904	1.5134	-.2601	1.5356	-9.75	-3.7253	-170.25
.902	1.5125	-.2590	1.5345	-9.72	-3.7195	-170.28

NEGATIVE DEFICIENCY

R	X	Y	GD	PHASE	1/GD(DB)	THETA
.900	1.5117	-.2578	1.5335	-9.68	-3.7137	-170.32
.898	1.5108	-.2567	1.5325	-9.64	-3.7078	-170.36
.896	1.5100	-.2555	1.5314	-9.61	-3.7020	-170.39
.894	1.5091	-.2544	1.5304	-9.57	-3.6961	-170.43
.892	1.5083	-.2533	1.5294	-9.53	-3.6903	-170.47
.890	1.5074	-.2521	1.5283	-9.50	-3.6844	-170.50
.888	1.5065	-.2510	1.5273	-9.46	-3.6785	-170.54
.886	1.5057	-.2499	1.5263	-9.42	-3.6726	-170.58
.884	1.5048	-.2487	1.5252	-9.39	-3.6667	-170.61
.882	1.5039	-.2476	1.5242	-9.35	-3.6608	-170.65
.880	1.5031	-.2465	1.5232	-9.31	-3.6549	-170.69
.878	1.5022	-.2454	1.5221	-9.28	-3.6490	-170.72
.876	1.5013	-.2443	1.5211	-9.24	-3.6430	-170.76
.874	1.5005	-.2431	1.5200	-9.20	-3.6371	-170.80
.872	1.4996	-.2420	1.5190	-9.17	-3.6311	-170.83
.870	1.4987	-.2409	1.5180	-9.13	-3.6252	-170.87
.868	1.4978	-.2398	1.5169	-9.10	-3.6192	-170.90
.866	1.4969	-.2387	1.5159	-9.06	-3.6132	-170.94
.864	1.4961	-.2376	1.5148	-9.02	-3.6072	-170.98
.862	1.4952	-.2365	1.5138	-8.99	-3.6012	-171.01
.860	1.4943	-.2354	1.5127	-8.95	-3.5952	-171.05
.858	1.4934	-.2343	1.5117	-8.92	-3.5892	-171.08
.856	1.4925	-.2332	1.5106	-8.88	-3.5831	-171.12
.854	1.4916	-.2321	1.5096	-8.85	-3.5771	-171.15
.852	1.4907	-.2311	1.5085	-8.81	-3.5710	-171.19
.850	1.4898	-.2300	1.5075	-8.78	-3.5650	-171.22
.848	1.4889	-.2289	1.5064	-8.74	-3.5589	-171.26
.846	1.4880	-.2278	1.5054	-8.70	-3.5528	-171.30
.844	1.4871	-.2267	1.5043	-8.67	-3.5467	-171.33
.842	1.4862	-.2257	1.5032	-8.63	-3.5406	-171.37
.840	1.4853	-.2246	1.5022	-8.60	-3.5345	-171.40
.838	1.4844	-.2235	1.5011	-8.56	-3.5284	-171.44
.836	1.4835	-.2225	1.5001	-8.53	-3.5223	-171.47
.834	1.4826	-.2214	1.4990	-8.49	-3.5161	-171.51
.832	1.4817	-.2203	1.4980	-8.46	-3.5100	-171.54
.830	1.4807	-.2193	1.4969	-8.42	-3.5038	-171.58
.828	1.4798	-.2182	1.4958	-8.39	-3.4976	-171.61
.826	1.4789	-.2172	1.4948	-8.35	-3.4915	-171.65
.824	1.4780	-.2161	1.4937	-8.32	-3.4853	-171.68
.822	1.4771	-.2151	1.4926	-8.28	-3.4791	-171.72
.820	1.4761	-.2140	1.4916	-8.25	-3.4729	-171.75
.818	1.4752	-.2130	1.4905	-8.22	-3.4667	-171.78
.816	1.4743	-.2119	1.4894	-8.18	-3.4604	-171.82
.814	1.4733	-.2109	1.4884	-8.15	-3.4542	-171.85
.812	1.4724	-.2099	1.4873	-8.11	-3.4479	-171.89
.810	1.4715	-.2088	1.4862	-8.08	-3.4417	-171.92
.808	1.4705	-.2078	1.4852	-8.04	-3.4354	-171.96
.806	1.4696	-.2068	1.4841	-8.01	-3.4291	-171.99
.804	1.4687	-.2058	1.4830	-7.98	-3.4229	-172.02
.802	1.4677	-.2047	1.4819	-7.94	-3.4166	-172.06

NEGATIVE DEFICIENCY

R	X	Y	GD	PHASE	1/GD(DB)	THETA
.800	1.4668	-.2037	1.4809	-7.91	-3.4103	-172.09
.798	1.4658	-.2027	1.4798	-7.87	-3.4039	-172.13
.796	1.4649	-.2017	1.4787	-7.84	-3.3976	-172.16
.794	1.4639	-.2007	1.4776	-7.81	-3.3913	-172.19
.792	1.4630	-.1997	1.4765	-7.77	-3.3849	-172.23
.790	1.4620	-.1987	1.4755	-7.74	-3.3786	-172.26
.788	1.4611	-.1977	1.4744	-7.70	-3.3722	-172.30
.786	1.4601	-.1967	1.4733	-7.67	-3.3658	-172.33
.784	1.4592	-.1957	1.4722	-7.64	-3.3595	-172.36
.782	1.4582	-.1947	1.4711	-7.60	-3.3531	-172.40
.780	1.4572	-.1937	1.4701	-7.57	-3.3467	-172.43
.778	1.4563	-.1927	1.4690	-7.54	-3.3403	-172.46
.776	1.4553	-.1917	1.4679	-7.50	-3.3338	-172.50
.774	1.4543	-.1907	1.4668	-7.47	-3.3274	-172.53
.772	1.4534	-.1897	1.4657	-7.44	-3.3210	-172.56
.770	1.4524	-.1887	1.4646	-7.40	-3.3145	-172.60
.768	1.4514	-.1877	1.4635	-7.37	-3.3080	-172.63
.766	1.4505	-.1868	1.4624	-7.34	-3.3016	-172.66
.764	1.4495	-.1858	1.4613	-7.30	-3.2951	-172.70
.762	1.4485	-.1848	1.4603	-7.27	-3.2886	-172.73
.760	1.4475	-.1839	1.4592	-7.24	-3.2821	-172.76
.758	1.4466	-.1829	1.4581	-7.21	-3.2756	-172.79
.756	1.4456	-.1819	1.4570	-7.17	-3.2691	-172.83
.754	1.4446	-.1810	1.4559	-7.14	-3.2625	-172.86
.752	1.4436	-.1800	1.4548	-7.11	-3.2560	-172.89
.750	1.4426	-.1790	1.4537	-7.07	-3.2494	-172.92
.748	1.4416	-.1781	1.4526	-7.04	-3.2429	-172.96
.746	1.4406	-.1771	1.4515	-7.01	-3.2363	-172.99
.744	1.4397	-.1762	1.4504	-6.98	-3.2297	-173.02
.742	1.4387	-.1752	1.4493	-6.95	-3.2231	-173.05
.740	1.4377	-.1743	1.4482	-6.91	-3.2165	-173.09
.738	1.4367	-.1734	1.4471	-6.88	-3.2099	-173.12
.736	1.4357	-.1724	1.4460	-6.85	-3.2033	-173.15
.734	1.4347	-.1715	1.4449	-6.82	-3.1967	-173.18
.732	1.4337	-.1706	1.4438	-6.78	-3.1900	-173.22
.730	1.4327	-.1696	1.4427	-6.75	-3.1834	-173.25
.728	1.4317	-.1687	1.4416	-6.72	-3.1767	-173.28
.726	1.4307	-.1678	1.4405	-6.69	-3.1700	-173.31
.724	1.4297	-.1669	1.4394	-6.66	-3.1634	-173.34
.722	1.4286	-.1659	1.4382	-6.62	-3.1567	-173.38
.720	1.4276	-.1650	1.4371	-6.59	-3.1500	-173.41
.718	1.4266	-.1641	1.4360	-6.56	-3.1433	-173.44
.716	1.4256	-.1632	1.4349	-6.53	-3.1365	-173.47
.714	1.4246	-.1623	1.4338	-6.50	-3.1298	-173.50
.712	1.4236	-.1614	1.4327	-6.47	-3.1231	-173.53
.710	1.4226	-.1605	1.4316	-6.44	-3.1163	-173.56
.708	1.4215	-.1596	1.4305	-6.40	-3.1095	-173.60
.706	1.4205	-.1587	1.4294	-6.37	-3.1028	-173.63
.704	1.4195	-.1578	1.4282	-6.34	-3.0960	-173.66
.702	1.4185	-.1569	1.4271	-6.31	-3.0892	-173.69

NEGATIVE DEFICIENCY

R	X	Y	GD	PHASE	1/GD(DB)	THETA
.700	1.4174	-.1560	1.4260	-6.28	-3.0824	-173.72
.698	1.4164	-.1551	1.4249	-6.25	-3.0756	-173.75
.696	1.4154	-.1542	1.4238	-6.22	-3.0688	-173.78
.694	1.4144	-.1533	1.4226	-6.19	-3.0619	-173.81
.692	1.4133	-.1524	1.4215	-6.16	-3.0551	-173.84
.690	1.4123	-.1515	1.4204	-6.12	-3.0482	-173.88
.688	1.4113	-.1507	1.4193	-6.09	-3.0414	-173.91
.686	1.4102	-.1498	1.4182	-6.06	-3.0345	-173.94
.684	1.4092	-.1489	1.4170	-6.03	-3.0276	-173.97
.682	1.4082	-.1481	1.4159	-6.00	-3.0207	-174.00
.680	1.4071	-.1472	1.4148	-5.97	-3.0138	-174.03
.678	1.4061	-.1463	1.4137	-5.94	-3.0069	-174.06
.676	1.4050	-.1455	1.4125	-5.91	-3.0000	-174.09
.674	1.4040	-.1446	1.4114	-5.88	-2.9931	-174.12
.672	1.4029	-.1437	1.4103	-5.85	-2.9861	-174.15
.670	1.4019	-.1429	1.4092	-5.82	-2.9792	-174.18
.668	1.4008	-.1420	1.4080	-5.79	-2.9722	-174.21
.666	1.3998	-.1412	1.4069	-5.76	-2.9652	-174.24
.664	1.3987	-.1403	1.4058	-5.73	-2.9582	-174.27
.662	1.3977	-.1395	1.4046	-5.70	-2.9512	-174.30
.660	1.3966	-.1387	1.4035	-5.67	-2.9442	-174.33
.658	1.3956	-.1378	1.4024	-5.64	-2.9372	-174.36
.656	1.3945	-.1370	1.4012	-5.61	-2.9302	-174.39
.654	1.3935	-.1361	1.4001	-5.58	-2.9231	-174.42
.652	1.3924	-.1353	1.3990	-5.55	-2.9161	-174.45
.650	1.3913	-.1345	1.3978	-5.52	-2.9090	-174.48
.648	1.3903	-.1337	1.3967	-5.49	-2.9020	-174.51
.646	1.3892	-.1328	1.3955	-5.46	-2.8949	-174.54
.644	1.3881	-.1320	1.3944	-5.43	-2.8878	-174.57
.642	1.3871	-.1312	1.3933	-5.40	-2.8807	-174.60
.640	1.3860	-.1304	1.3921	-5.37	-2.8736	-174.63
.638	1.3849	-.1296	1.3910	-5.34	-2.8665	-174.66
.636	1.3839	-.1288	1.3898	-5.32	-2.8593	-174.68
.634	1.3828	-.1279	1.3887	-5.29	-2.8522	-174.71
.632	1.3817	-.1271	1.3876	-5.26	-2.8451	-174.74
.630	1.3807	-.1263	1.3864	-5.23	-2.8379	-174.77
.628	1.3796	-.1255	1.3853	-5.20	-2.8307	-174.80
.626	1.3785	-.1247	1.3841	-5.17	-2.8235	-174.83
.624	1.3774	-.1239	1.3830	-5.14	-2.8163	-174.86
.622	1.3763	-.1231	1.3818	-5.11	-2.8091	-174.89
.620	1.3753	-.1224	1.3807	-5.08	-2.8019	-174.92
.618	1.3742	-.1216	1.3795	-5.06	-2.7947	-174.94
.616	1.3731	-.1208	1.3784	-5.03	-2.7875	-174.97
.614	1.3720	-.1200	1.3772	-5.00	-2.7802	-175.00
.612	1.3709	-.1192	1.3761	-4.97	-2.7730	-175.03
.610	1.3698	-.1184	1.3749	-4.94	-2.7657	-175.06
.608	1.3687	-.1177	1.3738	-4.91	-2.7584	-175.09
.606	1.3677	-.1169	1.3726	-4.89	-2.7511	-175.11
.604	1.3666	-.1161	1.3715	-4.86	-2.7438	-175.14
.602	1.3655	-.1154	1.3703	-4.83	-2.7365	-175.17

NEGATIVE DEFICIENCY

R	X	Y	GD	PHASE	1/GD(DB)	THETA
.600	1.3644	-.1146	1.3692	-4.80	-2.7292	-175.20
.598	1.3633	-.1138	1.3680	-4.77	-2.7219	-175.23
.596	1.3622	-.1131	1.3669	-4.74	-2.7145	-175.26
.594	1.3611	-.1123	1.3657	-4.72	-2.7072	-175.28
.592	1.3600	-.1116	1.3646	-4.69	-2.6998	-175.31
.590	1.3589	-.1108	1.3634	-4.66	-2.6925	-175.34
.588	1.3578	-.1101	1.3622	-4.63	-2.6851	-175.37
.586	1.3567	-.1093	1.3611	-4.61	-2.6777	-175.39
.584	1.3556	-.1086	1.3599	-4.58	-2.6703	-175.42
.582	1.3545	-.1078	1.3588	-4.55	-2.6629	-175.45
.580	1.3534	-.1071	1.3576	-4.52	-2.6554	-175.48
.578	1.3523	-.1063	1.3564	-4.50	-2.6480	-175.50
.576	1.3512	-.1056	1.3553	-4.47	-2.6406	-175.53
.574	1.3500	-.1049	1.3541	-4.44	-2.6331	-175.56
.572	1.3489	-.1041	1.3529	-4.41	-2.6256	-175.59
.570	1.3478	-.1034	1.3518	-4.39	-2.6182	-175.61
.568	1.3467	-.1027	1.3506	-4.36	-2.6107	-175.64
.566	1.3456	-.1020	1.3495	-4.33	-2.6032	-175.67
.564	1.3445	-.1013	1.3483	-4.31	-2.5957	-175.69
.562	1.3434	-.1005	1.3471	-4.28	-2.5881	-175.72
.560	1.3422	-.0998	1.3460	-4.25	-2.5806	-175.75
.558	1.3411	-.0991	1.3448	-4.23	-2.5731	-175.77
.556	1.3400	-.0984	1.3436	-4.20	-2.5655	-175.80
.554	1.3389	-.0977	1.3424	-4.17	-2.5579	-175.83
.552	1.3378	-.0970	1.3413	-4.15	-2.5504	-175.85
.550	1.3366	-.0963	1.3401	-4.12	-2.5428	-175.88
.548	1.3355	-.0956	1.3389	-4.09	-2.5352	-175.91
.546	1.3344	-.0949	1.3378	-4.07	-2.5276	-175.93
.544	1.3333	-.0942	1.3366	-4.04	-2.5199	-175.96
.542	1.3321	-.0935	1.3354	-4.02	-2.5123	-175.98
.540	1.3310	-.0928	1.3342	-3.99	-2.5047	-176.01
.538	1.3299	-.0921	1.3331	-3.96	-2.4970	-176.04
.536	1.3287	-.0914	1.3319	-3.94	-2.4894	-176.06
.534	1.3276	-.0908	1.3307	-3.91	-2.4817	-176.09
.532	1.3265	-.0901	1.3295	-3.89	-2.4740	-176.11
.530	1.3253	-.0894	1.3284	-3.86	-2.4663	-176.14
.528	1.3242	-.0887	1.3272	-3.83	-2.4586	-176.17
.526	1.3231	-.0881	1.3260	-3.81	-2.4509	-176.19
.524	1.3219	-.0874	1.3248	-3.78	-2.4431	-176.22
.522	1.3208	-.0867	1.3236	-3.76	-2.4354	-176.24
.520	1.3197	-.0861	1.3225	-3.73	-2.4277	-176.27
.518	1.3185	-.0854	1.3213	-3.71	-2.4199	-176.29
.516	1.3174	-.0848	1.3201	-3.68	-2.4121	-176.32
.514	1.3162	-.0841	1.3189	-3.66	-2.4043	-176.34
.512	1.3151	-.0834	1.3177	-3.63	-2.3965	-176.37
.510	1.3139	-.0828	1.3165	-3.61	-2.3887	-176.39
.508	1.3128	-.0821	1.3154	-3.58	-2.3809	-176.42
.506	1.3116	-.0815	1.3142	-3.56	-2.3731	-176.44
.504	1.3105	-.0809	1.3130	-3.53	-2.3652	-176.47
.502	1.3094	-.0802	1.3118	-3.51	-2.3574	-176.49

NEGATIVE DEFICIENCY

R	X	Y	GD	PHASE	1/GD(DB)	THETA
.500	1.3082	-.0796	1.3106	-3.48	-2.3495	-176.52
.498	1.3071	-.0789	1.3094	-3.46	-2.3417	-176.54
.496	1.3059	-.0783	1.3082	-3.43	-2.3338	-176.57
.494	1.3047	-.0777	1.3071	-3.41	-2.3259	-176.59
.492	1.3036	-.0771	1.3059	-3.38	-2.3180	-176.62
.490	1.3024	-.0764	1.3047	-3.36	-2.3101	-176.64
.488	1.3013	-.0758	1.3035	-3.33	-2.3021	-176.67
.486	1.3001	-.0752	1.3023	-3.31	-2.2942	-176.69
.484	1.2990	-.0746	1.3011	-3.29	-2.2862	-176.71
.482	1.2978	-.0740	1.2999	-3.26	-2.2783	-176.74
.480	1.2966	-.0733	1.2987	-3.24	-2.2703	-176.76
.478	1.2955	-.0727	1.2975	-3.21	-2.2623	-176.79
.476	1.2943	-.0721	1.2963	-3.19	-2.2543	-176.81
.474	1.2932	-.0715	1.2951	-3.17	-2.2463	-176.83
.472	1.2920	-.0709	1.2939	-3.14	-2.2383	-176.86
.470	1.2908	-.0703	1.2927	-3.12	-2.2303	-176.88
.468	1.2897	-.0697	1.2915	-3.09	-2.2222	-176.91
.466	1.2885	-.0691	1.2904	-3.07	-2.2142	-176.93
.464	1.2873	-.0685	1.2892	-3.05	-2.2061	-176.95
.462	1.2862	-.0679	1.2880	-3.02	-2.1980	-176.98
.460	1.2850	-.0674	1.2868	-3.00	-2.1899	-177.00
.458	1.2838	-.0668	1.2856	-2.98	-2.1818	-177.02
.456	1.2827	-.0662	1.2844	-2.95	-2.1737	-177.05
.454	1.2815	-.0656	1.2832	-2.93	-2.1656	-177.07
.452	1.2803	-.0650	1.2820	-2.91	-2.1575	-177.09
.450	1.2791	-.0645	1.2808	-2.88	-2.1493	-177.12
.448	1.2780	-.0639	1.2796	-2.86	-2.1412	-177.14
.446	1.2768	-.0633	1.2784	-2.84	-2.1330	-177.16
.444	1.2756	-.0628	1.2771	-2.82	-2.1248	-177.18
.442	1.2744	-.0622	1.2759	-2.79	-2.1166	-177.21
.440	1.2732	-.0616	1.2747	-2.77	-2.1084	-177.23
.438	1.2721	-.0611	1.2735	-2.75	-2.1002	-177.25
.436	1.2709	-.0605	1.2723	-2.73	-2.0920	-177.27
.434	1.2697	-.0600	1.2711	-2.70	-2.0838	-177.30
.432	1.2685	-.0594	1.2699	-2.68	-2.0755	-177.32
.430	1.2673	-.0589	1.2687	-2.66	-2.0672	-177.34
.428	1.2662	-.0583	1.2675	-2.64	-2.0590	-177.36
.426	1.2650	-.0578	1.2663	-2.61	-2.0507	-177.39
.424	1.2638	-.0572	1.2651	-2.59	-2.0424	-177.41
.422	1.2626	-.0567	1.2639	-2.57	-2.0341	-177.43
.420	1.2614	-.0561	1.2627	-2.55	-2.0258	-177.45
.418	1.2602	-.0556	1.2615	-2.53	-2.0174	-177.47
.416	1.2590	-.0551	1.2602	-2.51	-2.0091	-177.49
.414	1.2579	-.0546	1.2590	-2.48	-2.0007	-177.52
.412	1.2567	-.0540	1.2578	-2.46	-1.9924	-177.54
.410	1.2555	-.0535	1.2566	-2.44	-1.9840	-177.56
.408	1.2543	-.0530	1.2554	-2.42	-1.9756	-177.58
.406	1.2531	-.0525	1.2542	-2.40	-1.9672	-177.60
.404	1.2519	-.0520	1.2530	-2.38	-1.9588	-177.62
.402	1.2507	-.0514	1.2518	-2.36	-1.9504	-177.64

NEGATIVE DEFICIENCY

R	X	Y	GD	PHASE	1/GD(DB)	THETA
.400	1.2495	-.0509	1.2505	-2.33	-1.9420	-177.67
.398	1.2483	-.0504	1.2493	-2.31	-1.9335	-177.69
.396	1.2471	-.0499	1.2481	-2.29	-1.9250	-177.71
.394	1.2459	-.0494	1.2469	-2.27	-1.9166	-177.73
.392	1.2447	-.0489	1.2457	-2.25	-1.9081	-177.75
.390	1.2435	-.0484	1.2445	-2.23	-1.8996	-177.77
.388	1.2423	-.0479	1.2432	-2.21	-1.8911	-177.79
.386	1.2411	-.0474	1.2420	-2.19	-1.8826	-177.81
.384	1.2399	-.0469	1.2408	-2.17	-1.8740	-177.83
.382	1.2387	-.0464	1.2396	-2.15	-1.8655	-177.85
.380	1.2375	-.0460	1.2384	-2.13	-1.8569	-177.87
.378	1.2363	-.0455	1.2371	-2.11	-1.8484	-177.89
.376	1.2351	-.0450	1.2359	-2.09	-1.8398	-177.91
.374	1.2339	-.0445	1.2347	-2.07	-1.8312	-177.93
.372	1.2327	-.0440	1.2335	-2.05	-1.8226	-177.95
.370	1.2315	-.0436	1.2323	-2.03	-1.8140	-177.97
.368	1.2303	-.0431	1.2310	-2.01	-1.8054	-177.99
.366	1.2291	-.0426	1.2298	-1.99	-1.7967	-178.01
.364	1.2279	-.0422	1.2286	-1.97	-1.7881	-178.03
.362	1.2266	-.0417	1.2274	-1.95	-1.7794	-178.05
.360	1.2254	-.0413	1.2261	-1.93	-1.7708	-178.07
.358	1.2242	-.0408	1.2249	-1.91	-1.7621	-178.09
.356	1.2230	-.0403	1.2237	-1.89	-1.7534	-178.11
.354	1.2218	-.0399	1.2225	-1.87	-1.7447	-178.13
.352	1.2206	-.0394	1.2212	-1.85	-1.7359	-178.15
.350	1.2194	-.0390	1.2200	-1.83	-1.7272	-178.17
.348	1.2182	-.0385	1.2188	-1.81	-1.7185	-178.19
.346	1.2169	-.0381	1.2175	-1.79	-1.7097	-178.21
.344	1.2157	-.0377	1.2163	-1.77	-1.7009	-178.23
.342	1.2145	-.0372	1.2151	-1.76	-1.6921	-178.24
.340	1.2133	-.0368	1.2139	-1.74	-1.6834	-178.26
.338	1.2121	-.0364	1.2126	-1.72	-1.6745	-178.28
.336	1.2109	-.0359	1.2114	-1.70	-1.6657	-178.30
.334	1.2096	-.0355	1.2102	-1.68	-1.6569	-178.32
.332	1.2084	-.0351	1.2089	-1.66	-1.6481	-178.34
.330	1.2072	-.0347	1.2077	-1.64	-1.6392	-178.36
.328	1.2060	-.0342	1.2065	-1.63	-1.6303	-178.37
.326	1.2048	-.0338	1.2052	-1.61	-1.6214	-178.39
.324	1.2035	-.0334	1.2040	-1.59	-1.6126	-178.41
.322	1.2023	-.0330	1.2028	-1.57	-1.6036	-178.43
.320	1.2011	-.0326	1.2015	-1.55	-1.5947	-178.45
.318	1.1999	-.0322	1.2003	-1.54	-1.5858	-178.46
.316	1.1986	-.0318	1.1991	-1.52	-1.5769	-178.48
.314	1.1974	-.0314	1.1978	-1.50	-1.5679	-178.50
.312	1.1962	-.0310	1.1966	-1.48	-1.5589	-178.52
.310	1.1950	-.0306	1.1954	-1.47	-1.5500	-178.53
.308	1.1937	-.0302	1.1941	-1.45	-1.5410	-178.55
.306	1.1925	-.0298	1.1929	-1.43	-1.5320	-178.57
.304	1.1913	-.0294	1.1916	-1.41	-1.5229	-178.59
.302	1.1901	-.0290	1.1904	-1.40	-1.5139	-178.60

NEGATIVE DEFICIENCY

R	X	Y	GD	PHASE	1/GD(DB)	THETA
.300	1.1888	-.0286	1.1892	-1.38	-1.5049	-178.62
.298	1.1876	-.0283	1.1879	-1.36	-1.4958	-178.64
.296	1.1864	-.0279	1.1867	-1.35	-1.4868	-178.65
.294	1.1851	-.0275	1.1855	-1.33	-1.4777	-178.67
.292	1.1839	-.0271	1.1842	-1.31	-1.4686	-178.69
.290	1.1827	-.0268	1.1830	-1.30	-1.4595	-178.70
.288	1.1814	-.0264	1.1817	-1.28	-1.4504	-178.72
.286	1.1802	-.0260	1.1805	-1.26	-1.4412	-178.74
.284	1.1790	-.0257	1.1792	-1.25	-1.4321	-178.75
.282	1.1777	-.0253	1.1780	-1.23	-1.4229	-178.77
.280	1.1765	-.0250	1.1768	-1.22	-1.4138	-178.78
.278	1.1753	-.0246	1.1755	-1.20	-1.4046	-178.80
.276	1.1740	-.0242	1.1743	-1.18	-1.3954	-178.82
.274	1.1728	-.0239	1.1730	-1.17	-1.3862	-178.83
.272	1.1716	-.0235	1.1718	-1.15	-1.3770	-178.85
.270	1.1703	-.0232	1.1705	-1.14	-1.3678	-178.86
.268	1.1691	-.0229	1.1693	-1.12	-1.3585	-178.88
.266	1.1678	-.0225	1.1681	-1.10	-1.3493	-178.90
.264	1.1666	-.0222	1.1668	-1.09	-1.3400	-178.91
.262	1.1654	-.0219	1.1656	-1.07	-1.3307	-178.93
.260	1.1641	-.0215	1.1643	-1.06	-1.3214	-178.94
.258	1.1629	-.0212	1.1631	-1.04	-1.3121	-178.96
.256	1.1616	-.0209	1.1618	-1.03	-1.3028	-178.97
.254	1.1604	-.0205	1.1606	-1.01	-1.2935	-178.99
.252	1.1591	-.0202	1.1593	-1.00	-1.2841	-179.00
.250	1.1579	-.0199	1.1581	-.98	-1.2748	-179.02
.248	1.1567	-.0196	1.1568	-.97	-1.2654	-179.03
.246	1.1554	-.0193	1.1556	-.96	-1.2560	-179.04
.244	1.1542	-.0190	1.1543	-.94	-1.2466	-179.06
.242	1.1529	-.0186	1.1531	-.93	-1.2372	-179.07
.240	1.1517	-.0183	1.1518	-.91	-1.2278	-179.09
.238	1.1504	-.0180	1.1506	-.90	-1.2183	-179.10
.236	1.1492	-.0177	1.1493	-.88	-1.2089	-179.12
.234	1.1479	-.0174	1.1481	-.87	-1.1994	-179.13
.232	1.1467	-.0171	1.1468	-.86	-1.1900	-179.14
.230	1.1455	-.0168	1.1456	-.84	-1.1805	-179.16
.228	1.1442	-.0165	1.1443	-.83	-1.1710	-179.17
.226	1.1430	-.0163	1.1431	-.81	-1.1615	-179.19
.224	1.1417	-.0160	1.1418	-.80	-1.1519	-179.20
.222	1.1405	-.0157	1.1406	-.79	-1.1424	-179.21
.220	1.1392	-.0154	1.1393	-.77	-1.1328	-179.23
.218	1.1380	-.0151	1.1381	-.76	-1.1233	-179.24
.216	1.1367	-.0149	1.1368	-.75	-1.1137	-179.25
.214	1.1355	-.0146	1.1355	-.74	-1.1041	-179.26
.212	1.1342	-.0143	1.1343	-.72	-1.0945	-179.28
.210	1.1330	-.0140	1.1330	-.71	-1.0849	-179.29
.208	1.1317	-.0138	1.1318	-.70	-1.0753	-179.30
.206	1.1304	-.0135	1.1305	-.68	-1.0656	-179.32
.204	1.1292	-.0132	1.1293	-.67	-1.0560	-179.33
.202	1.1279	-.0130	1.1280	-.66	-1.0463	-179.34

NEGATIVE DEFICIENCY

R	X	Y	GD	PHASE	1/GD(DB)	THETA
.200	1.1267	-.0127	1.1268	-.65	-1.0366	-179.35
.198	1.1254	-.0125	1.1255	-.64	-1.0269	-179.36
.196	1.1242	-.0122	1.1242	-.62	-1.0172	-179.38
.194	1.1229	-.0120	1.1230	-.61	-1.0075	-179.39
.192	1.1217	-.0117	1.1217	-.60	-.9977	-179.40
.190	1.1204	-.0115	1.1205	-.59	-.9880	-179.41
.188	1.1192	-.0113	1.1192	-.58	-.9782	-179.42
.186	1.1179	-.0110	1.1180	-.56	-.9685	-179.44
.184	1.1166	-.0108	1.1167	-.55	-.9587	-179.45
.182	1.1154	-.0105	1.1154	-.54	-.9489	-179.46
.180	1.1141	-.0103	1.1142	-.53	-.9391	-179.47
.178	1.1129	-.0101	1.1129	-.52	-.9292	-179.48
.176	1.1116	-.0099	1.1117	-.51	-.9194	-179.49
.174	1.1104	-.0096	1.1104	-.50	-.9095	-179.50
.172	1.1091	-.0094	1.1091	-.49	-.8997	-179.51
.170	1.1078	-.0092	1.1079	-.48	-.8898	-179.52
.168	1.1066	-.0090	1.1066	-.47	-.8799	-179.53
.166	1.1053	-.0088	1.1053	-.45	-.8700	-179.55
.164	1.1041	-.0086	1.1041	-.44	-.8601	-179.56
.162	1.1028	-.0084	1.1028	-.43	-.8501	-179.57
.160	1.1015	-.0081	1.1016	-.42	-.8402	-179.58
.158	1.1003	-.0079	1.1003	-.41	-.8302	-179.59
.156	1.0990	-.0077	1.0990	-.40	-.8202	-179.60
.154	1.0977	-.0075	1.0978	-.39	-.8103	-179.61
.152	1.0965	-.0074	1.0965	-.38	-.8003	-179.62
.150	1.0952	-.0072	1.0952	-.37	-.7902	-179.63
.148	1.0940	-.0070	1.0940	-.37	-.7802	-179.63
.146	1.0927	-.0068	1.0927	-.36	-.7702	-179.64
.144	1.0914	-.0066	1.0915	-.35	-.7601	-179.65
.142	1.0902	-.0064	1.0902	-.34	-.7500	-179.66
.140	1.0889	-.0062	1.0889	-.33	-.7400	-179.67
.138	1.0876	-.0061	1.0877	-.32	-.7299	-179.68
.136	1.0864	-.0059	1.0864	-.31	-.7198	-179.69
.134	1.0851	-.0057	1.0851	-.30	-.7096	-179.70
.132	1.0839	-.0055	1.0839	-.29	-.6995	-179.71
.130	1.0826	-.0054	1.0826	-.28	-.6894	-179.72
.128	1.0813	-.0052	1.0813	-.28	-.6792	-179.72
.126	1.0801	-.0051	1.0801	-.27	-.6690	-179.73
.124	1.0788	-.0049	1.0788	-.26	-.6588	-179.74
.122	1.0775	-.0047	1.0775	-.25	-.6486	-179.75
.120	1.0763	-.0046	1.0763	-.24	-.6384	-179.76
.118	1.0750	-.0044	1.0750	-.24	-.6282	-179.76
.116	1.0737	-.0043	1.0737	-.23	-.6179	-179.77
.114	1.0725	-.0041	1.0725	-.22	-.6077	-179.78
.112	1.0712	-.0040	1.0712	-.21	-.5974	-179.79
.110	1.0699	-.0039	1.0699	-.21	-.5871	-179.79
.108	1.0687	-.0037	1.0687	-.20	-.5768	-179.80
.106	1.0674	-.0036	1.0674	-.19	-.5665	-179.81
.104	1.0661	-.0034	1.0661	-.19	-.5562	-179.81
.102	1.0649	-.0033	1.0649	-.18	-.5458	-179.82

NEGATIVE DEFICIENCY

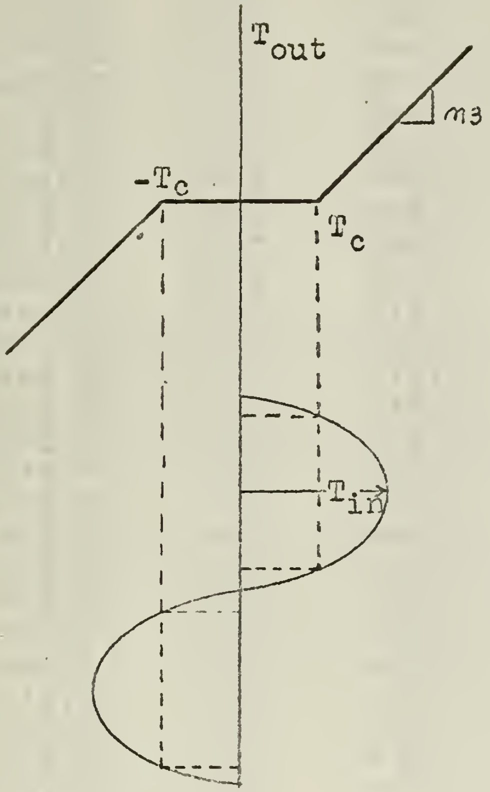
R	X	Y	GD	PHASE	1/GD(DB)	THETA
.100	1.0636	-.0032	1.0636	-.17	-.5355	-179.83
.098	1.0623	-.0031	1.0623	-.16	-.5251	-179.84
.096	1.0610	-.0029	1.0610	-.16	-.5147	-179.84
.094	1.0598	-.0028	1.0598	-.15	-.5043	-179.85
.092	1.0585	-.0027	1.0585	-.15	-.4939	-179.85
.090	1.0572	-.0026	1.0572	-.14	-.4835	-179.86
.088	1.0560	-.0025	1.0560	-.13	-.4730	-179.87
.086	1.0547	-.0024	1.0547	-.13	-.4626	-179.87
.084	1.0534	-.0022	1.0534	-.12	-.4521	-179.88
.082	1.0522	-.0021	1.0522	-.12	-.4416	-179.88
.080	1.0509	-.0020	1.0509	-.11	-.4312	-179.89
.078	1.0496	-.0019	1.0496	-.11	-.4206	-179.89
.076	1.0483	-.0018	1.0483	-.10	-.4101	-179.90
.074	1.0471	-.0017	1.0471	-.10	-.3996	-179.90
.072	1.0458	-.0017	1.0458	-.09	-.3890	-179.91
.070	1.0445	-.0016	1.0445	-.09	-.3785	-179.91
.068	1.0433	-.0015	1.0433	-.08	-.3679	-179.92
.066	1.0420	-.0014	1.0420	-.08	-.3573	-179.92
.064	1.0407	-.0013	1.0407	-.07	-.3467	-179.93
.062	1.0395	-.0012	1.0395	-.07	-.3361	-179.93
.060	1.0382	-.0011	1.0382	-.06	-.3255	-179.94
.058	1.0369	-.0011	1.0369	-.06	-.3148	-179.94
.056	1.0356	-.0010	1.0356	-.06	-.3042	-179.94
.054	1.0344	-.0009	1.0344	-.05	-.2935	-179.95
.052	1.0331	-.0009	1.0331	-.05	-.2828	-179.95
.050	1.0318	-.0008	1.0318	-.04	-.2721	-179.96
.048	1.0305	-.0007	1.0305	-.04	-.2614	-179.96
.046	1.0293	-.0007	1.0293	-.04	-.2506	-179.96
.044	1.0280	-.0006	1.0280	-.03	-.2399	-179.97
.042	1.0267	-.0006	1.0267	-.03	-.2291	-179.97
.040	1.0255	-.0005	1.0255	-.03	-.2184	-179.97
.038	1.0242	-.0005	1.0242	-.03	-.2076	-179.97
.036	1.0229	-.0004	1.0229	-.02	-.1968	-179.98
.034	1.0216	-.0004	1.0216	-.02	-.1860	-179.98
.032	1.0204	-.0003	1.0204	-.02	-.1751	-179.98
.030	1.0191	-.0003	1.0191	-.02	-.1643	-179.98
.028	1.0178	-.0002	1.0178	-.01	-.1535	-179.99
.026	1.0166	-.0002	1.0166	-.01	-.1426	-179.99
.024	1.0153	-.0002	1.0153	-.01	-.1317	-179.99
.022	1.0140	-.0002	1.0140	-.01	-.1208	-179.99
.020	1.0127	-.0001	1.0127	-.01	-.1099	-179.99
.018	1.0115	-.0001	1.0115	-.01	-.0990	-179.99
.016	1.0102	-.0001	1.0102	-.00	-.0880	-180.00
.014	1.0089	-.0001	1.0089	-.00	-.0771	-180.00
.012	1.0076	-.0000	1.0076	-.00	-.0661	-180.00
.010	1.0064	-.0000	1.0064	-.00	-.0551	-180.00
.008	1.0051	-.0000	1.0051	-.00	-.0441	-180.00
.006	1.0038	-.0000	1.0038	-.00	-.0331	-180.00
.004	1.0025	-.0000	1.0025	-.00	-.0221	-180.00
.002	1.0013	-.0000	1.0013	-.00	-.0111	-180.00

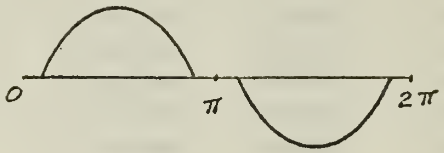
APPENDIX X

Coulomb Friction

Coulomb friction is present in varying degrees in all mechanical systems. This analysis considers only moving friction and neglects any static friction or stiction.

In the idealized nonlinearity shown in Figure X-1, if a torque is applied which is less than the maximum friction force the output velocity will be zero. Once the input torque exceeds the maximum friction force the system will have a resultant output torque which is proportional to the input torque minus the coulomb friction. The describing function (and the resultant data) for coulomb friction is identical to that for deadzone.



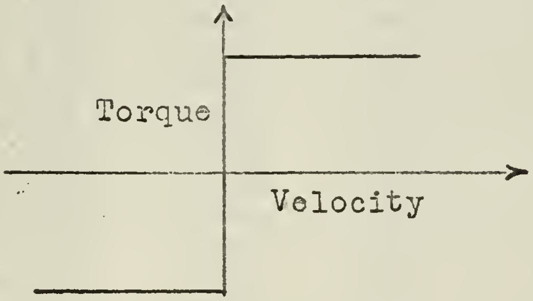


$$R = \frac{T_c}{T}$$

$$T_{in} = T \sin wt$$

$$T_{out} = 0 \quad 0 \quad wt$$
$$T_{out} = T_{in} - T_c \quad - \quad wt$$
$$T_{out} = 0 \quad wt$$

$$GD = \frac{2}{\pi}\left[\frac{\pi}{2} - \sin^{-1} R - R\sqrt{1-R^2}\right] \angle 0^\circ$$



COULOMB FRICTION

Figure X-1

COULOMB FRICTION

R	GD(JW)	1/GD (DB)	R	GD(JW)	1/GD (DB)
1.000	.0000	*	.900	.0374	28.5453
.998	.0001	79.1979	.898	.0385	28.2900
.996	.0003	70.2901	.896	.0396	28.0397
.994	.0006	65.0403	.894	.0408	27.7942
.992	.0009	61.3074	.892	.0419	27.5534
.990	.0012	58.4095	.890	.0431	27.3171
.988	.0016	56.0407	.888	.0442	27.0850
.986	.0020	54.0376	.886	.0454	26.8571
.984	.0024	52.3023	.884	.0466	26.6333
.982	.0029	50.7717	.882	.0478	26.4133
.980	.0034	49.4026	.880	.0490	26.1970
.978	.0039	48.1642	.878	.0502	25.9844
.976	.0044	47.0338	.876	.0514	25.7752
.974	.0050	45.9941	.874	.0527	25.5695
.972	.0056	45.0316	.872	.0539	25.3671
.970	.0062	44.1357	.870	.0552	25.1678
.968	.0068	43.2978	.868	.0564	24.9716
.966	.0075	42.5108	.866	.0577	24.7784
.964	.0082	41.7690	.864	.0590	24.5881
.962	.0088	41.0674	.862	.0603	24.4006
.960	.0095	40.4019	.860	.0615	24.2159
.958	.0103	39.7690	.858	.0629	24.0338
.956	.0110	39.1657	.856	.0642	23.8544
.954	.0118	38.5893	.854	.0655	23.6774
.952	.0125	38.0375	.852	.0668	23.5029
.950	.0133	37.5084	.850	.0681	23.3307
.948	.0141	37.0001	.848	.0695	23.1609
.946	.0149	36.5112	.846	.0708	22.9933
.944	.0158	36.0401	.844	.0722	22.8280
.942	.0166	35.5856	.842	.0736	22.6648
.940	.0175	35.1466	.840	.0750	22.5036
.938	.0184	34.7221	.838	.0763	22.3445
.936	.0193	34.3112	.836	.0777	22.1874
.934	.0202	33.9130	.834	.0791	22.0323
.932	.0211	33.5267	.832	.0805	21.8790
.930	.0220	33.1517	.830	.0820	21.7276
.928	.0229	32.7874	.828	.0834	21.5779
.926	.0239	32.4331	.826	.0848	21.4301
.924	.0249	32.0884	.824	.0863	21.2840
.922	.0258	31.7527	.822	.0877	21.1395
.920	.0268	31.4255	.820	.0892	20.9967
.918	.0278	31.1065	.818	.0906	20.8555
.916	.0289	30.7952	.816	.0921	20.7159
.914	.0299	30.4914	.814	.0936	20.5778
.912	.0309	30.1946	.812	.0950	20.4413
.910	.0320	29.9045	.810	.0965	20.3062
.908	.0330	29.6208	.808	.0980	20.1725
.906	.0341	29.3433	.806	.0995	20.0403
.904	.0352	29.0717	.804	.1010	19.9094
.902	.0363	28.8058	.802	.1026	19.7800

COULOMB FRICTION

R	GD(JW)	1/GD (DB)	R	GD(JW)	1/GD (DB)
.800	.1041	19.6518	.700	.1881	14.5112
.798	.1056	19.5250	.698	.1899	14.4275
.796	.1072	19.3994	.696	.1918	14.3444
.794	.1087	19.2751	.694	.1936	14.2619
.792	.1103	19.1520	.692	.1954	14.1799
.790	.1118	19.0301	.690	.1973	14.0985
.788	.1134	18.9094	.688	.1991	14.0176
.786	.1149	18.7899	.686	.2010	13.9373
.784	.1165	18.6715	.684	.2028	13.8574
.782	.1181	18.5542	.682	.2047	13.7782
.780	.1197	18.4381	.680	.2066	13.6994
.778	.1213	18.3230	.678	.2084	13.6211
.776	.1229	18.2089	.676	.2103	13.5434
.774	.1245	18.0959	.674	.2122	13.4661
.772	.1261	17.9840	.672	.2141	13.3893
.770	.1277	17.8730	.670	.2159	13.3131
.768	.1294	17.7630	.668	.2178	13.2373
.766	.1310	17.6540	.666	.2197	13.1619
.764	.1326	17.5459	.664	.2216	13.0871
.762	.1343	17.4388	.662	.2235	13.0127
.760	.1359	17.3326	.660	.2255	12.9388
.758	.1376	17.2273	.658	.2274	12.8653
.756	.1393	17.1229	.656	.2293	12.7923
.754	.1409	17.0194	.654	.2312	12.7197
.752	.1426	16.9167	.652	.2331	12.6475
.750	.1443	16.8149	.650	.2351	12.5758
.748	.1460	16.7140	.648	.2370	12.5045
.746	.1477	16.6138	.646	.2390	12.4337
.744	.1494	16.5145	.644	.2409	12.3632
.742	.1511	16.4159	.642	.2429	12.2932
.740	.1528	16.3182	.640	.2448	12.2235
.738	.1545	16.2212	.638	.2468	12.1543
.736	.1562	16.1250	.636	.2487	12.0855
.734	.1580	16.0295	.634	.2507	12.0171
.732	.1597	15.9348	.632	.2527	11.9490
.730	.1614	15.8407	.630	.2546	11.8814
.728	.1632	15.7475	.628	.2566	11.8141
.726	.1649	15.6549	.626	.2586	11.7472
.724	.1667	15.5630	.624	.2606	11.6807
.722	.1684	15.4718	.622	.2626	11.6146
.720	.1702	15.3813	.620	.2646	11.5488
.718	.1720	15.2914	.618	.2666	11.4834
.716	.1737	15.2022	.616	.2686	11.4184
.714	.1755	15.1136	.614	.2706	11.3537
.712	.1773	15.0257	.612	.2726	11.2893
.710	.1791	14.9384	.610	.2746	11.2253
.708	.1809	14.8518	.608	.2766	11.1617
.706	.1827	14.7657	.606	.2787	11.0984
.704	.1845	14.6803	.604	.2807	11.0354
.702	.1863	14.5955	.602	.2827	10.9728

COULOMB FRICTION

R	GD(JW)	1/GD (DB)	R	GD(JW)	1/GD (DB)
.600	.2848	10.9105	.500	.3910	8.1564
.598	.2868	10.8485	.498	.3932	8.1075
.596	.2888	10.7868	.496	.3954	8.0588
.594	.2909	10.7255	.494	.3976	8.0104
.592	.2929	10.6645	.492	.3998	7.9621
.590	.2950	10.6038	.490	.4021	7.9140
.588	.2970	10.5434	.488	.4043	7.8662
.586	.2991	10.4833	.486	.4065	7.8185
.584	.3012	10.4236	.484	.4087	7.7711
.582	.3032	10.3641	.482	.4110	7.7238
.580	.3053	10.3049	.480	.4132	7.6768
.578	.3074	10.2461	.478	.4154	7.6299
.576	.3095	10.1875	.476	.4177	7.5832
.574	.3116	10.1292	.474	.4199	7.5368
.572	.3136	10.0712	.472	.4222	7.4905
.570	.3157	10.0135	.470	.4244	7.4444
.568	.3178	9.9561	.468	.4267	7.3985
.566	.3199	9.8990	.466	.4289	7.3528
.564	.3220	9.8421	.464	.4312	7.3072
.562	.3241	9.7856	.462	.4334	7.2619
.560	.3262	9.7292	.460	.4357	7.2167
.558	.3284	9.6732	.458	.4379	7.1717
.556	.3305	9.6174	.456	.4402	7.1269
.554	.3326	9.5619	.454	.4425	7.0823
.552	.3347	9.5067	.452	.4447	7.0378
.550	.3368	9.4517	.450	.4470	6.9936
.548	.3390	9.3970	.448	.4493	6.9495
.546	.3411	9.3426	.446	.4516	6.9055
.544	.3432	9.2884	.444	.4538	6.8618
.542	.3454	9.2344	.442	.4561	6.8182
.540	.3475	9.1807	.440	.4584	6.7748
.538	.3497	9.1273	.438	.4607	6.7315
.536	.3518	9.0741	.436	.4630	6.6885
.534	.3540	9.0211	.434	.4653	6.6455
.532	.3561	8.9684	.432	.4676	6.6028
.530	.3583	8.9159	.430	.4699	6.5602
.528	.3604	8.8637	.428	.4722	6.5178
.526	.3626	8.8117	.426	.4745	6.4756
.524	.3648	8.7599	.424	.4768	6.4335
.522	.3669	8.7084	.422	.4791	6.3915
.520	.3691	8.6571	.420	.4814	6.3497
.518	.3713	8.6060	.418	.4837	6.3081
.516	.3735	8.5552	.416	.4860	6.2667
.514	.3756	8.5046	.414	.4884	6.2254
.512	.3778	8.4542	.412	.4907	6.1842
.510	.3800	8.4040	.410	.4930	6.1432
.508	.3822	8.3540	.408	.4953	6.1024
.506	.3844	8.3043	.406	.4976	6.0617
.504	.3866	8.2548	.404	.5000	6.0211
.502	.3888	8.2055	.402	.5023	5.9807

COULOMB FRICTION

R	GD(JW)	1/GD (DB)	R	GD(JW)	1/GD (DB)
.400	.5046	5.9405	.300	.6238	4.0986
.398	.5070	5.9004	.298	.6263	4.0648
.396	.5093	5.8604	.296	.6287	4.0311
.394	.5116	5.8206	.294	.6311	3.9976
.392	.5140	5.7810	.292	.6336	3.9641
.390	.5163	5.7415	.290	.6360	3.9308
.388	.5187	5.7021	.288	.6384	3.8976
.386	.5210	5.6629	.286	.6409	3.8644
.384	.5234	5.6238	.284	.6433	3.8314
.382	.5257	5.5848	.282	.6458	3.7985
.380	.5281	5.5460	.280	.6482	3.7657
.378	.5304	5.5073	.278	.6507	3.7330
.376	.5328	5.4688	.276	.6531	3.7004
.374	.5352	5.4304	.274	.6555	3.6679
.372	.5375	5.3921	.272	.6580	3.6355
.370	.5399	5.3540	.270	.6604	3.6032
.368	.5423	5.3160	.268	.6629	3.5710
.366	.5446	5.2781	.266	.6654	3.5389
.364	.5470	5.2404	.264	.6678	3.5069
.362	.5494	5.2028	.262	.6703	3.4750
.360	.5517	5.1653	.260	.6727	3.4432
.358	.5541	5.1280	.258	.6752	3.4115
.356	.5565	5.0908	.256	.6776	3.3799
.354	.5589	5.0537	.254	.6801	3.3484
.352	.5613	5.0168	.252	.6826	3.3170
.350	.5636	4.9800	.250	.6850	3.2857
.348	.5660	4.9433	.248	.6875	3.2545
.346	.5684	4.9067	.246	.6900	3.2234
.344	.5708	4.8702	.244	.6924	3.1923
.342	.5732	4.8339	.242	.6949	3.1614
.340	.5756	4.7977	.240	.6974	3.1306
.338	.5780	4.7616	.238	.6999	3.0998
.336	.5804	4.7257	.236	.7023	3.0692
.334	.5828	4.6899	.234	.7048	3.0386
.332	.5852	4.6541	.232	.7073	3.0082
.330	.5876	4.6185	.230	.7098	2.9778
.328	.5900	4.5831	.228	.7122	2.9475
.326	.5924	4.5477	.226	.7147	2.9173
.324	.5948	4.5125	.224	.7172	2.8872
.322	.5972	4.4774	.222	.7197	2.8572
.320	.5996	4.4424	.220	.7222	2.8273
.318	.6020	4.4075	.218	.7246	2.7974
.316	.6045	4.3727	.216	.7271	2.7677
.314	.6069	4.3380	.214	.7296	2.7380
.312	.6093	4.3035	.212	.7321	2.7085
.310	.6117	4.2690	.210	.7346	2.6790
.308	.6141	4.2347	.208	.7371	2.6496
.306	.6166	4.2005	.206	.7396	2.6203
.304	.6190	4.1664	.204	.7421	2.5911
.302	.6214	4.1324	.202	.7446	2.5619

COULOMB FRICTION

R	GD(JW)	1/GD (DB)	R	GD(JW)	1/GD (DB)
.200	.7471	2.5329	.100	.8729	1.1808
.198	.7496	2.5039	.098	.8754	1.1556
.196	.7521	2.4750	.096	.8780	1.1305
.194	.7546	2.4462	.094	.8805	1.1055
.192	.7570	2.4175	.092	.8830	1.0805
.190	.7595	2.3889	.090	.8856	1.0556
.188	.7620	2.3603	.088	.8881	1.0308
.186	.7646	2.3319	.086	.8906	1.0060
.184	.7671	2.3035	.084	.8932	.9813
.182	.7696	2.2752	.082	.8957	.9566
.180	.7721	2.2470	.080	.8982	.9321
.178	.7746	2.2188	.078	.9008	.9075
.176	.7771	2.1908	.076	.9033	.8831
.174	.7796	2.1628	.074	.9059	.8587
.172	.7821	2.1349	.072	.9084	.8344
.170	.7846	2.1071	.070	.9109	.8101
.168	.7871	2.0793	.068	.9135	.7860
.166	.7896	2.0517	.066	.9160	.7618
.164	.7921	2.0241	.064	.9186	.7378
.162	.7946	1.9966	.062	.9211	.7138
.160	.7972	1.9691	.060	.9237	.6898
.158	.7997	1.9418	.058	.9262	.6660
.156	.8022	1.9145	.056	.9287	.6422
.154	.8047	1.8873	.054	.9313	.6184
.152	.8072	1.8602	.052	.9338	.5947
.150	.8097	1.8332	.050	.9364	.5711
.148	.8123	1.8062	.048	.9389	.5475
.146	.8148	1.7793	.046	.9415	.5240
.144	.8173	1.7525	.044	.9440	.5006
.142	.8198	1.7257	.042	.9465	.4772
.140	.8223	1.6991	.040	.9491	.4539
.138	.8249	1.6725	.038	.9516	.4306
.136	.8274	1.6460	.036	.9542	.4075
.134	.8299	1.6195	.034	.9567	.3843
.132	.8324	1.5931	.032	.9593	.3612
.130	.8349	1.5668	.030	.9618	.3382
.128	.8375	1.5406	.028	.9644	.3153
.126	.8400	1.5144	.026	.9669	.2924
.124	.8425	1.4884	.024	.9694	.2695
.122	.8451	1.4623	.022	.9720	.2468
.120	.8476	1.4364	.020	.9745	.2240
.118	.8501	1.4105	.018	.9771	.2014
.116	.8526	1.3847	.016	.9796	.1788
.114	.8552	1.3590	.014	.9822	.1562
.112	.8577	1.3333	.012	.9847	.1337
.110	.8602	1.3077	.010	.9873	.1113
.108	.8628	1.2822	.008	.9898	.0889
.106	.8653	1.2568	.006	.9924	.0666
.104	.8678	1.2314	.004	.9949	.0443
.102	.8704	1.2061	.002	.9975	.0221

APPENDIX XI

Friction Controlled Backlash

In a gear box with backlash, if the inertia of the output member is small compared to that of the input member and the total friction is significant, then the output inertia may be ignored and the nonlinear element is said to be friction controlled. The result is that the velocity of the output member goes to zero whenever the input member reverses direction. The graph of the transfer function between input and output is shown in Fig. XI-1.

For a sine wave input $E \sin\omega t$ the output is

$$g(t) = k(E \sin\omega t - B/2) \qquad 0 < \omega t < \pi/2$$

$$g(t) = k(E - B/2) \qquad \pi/2 < \omega t < \pi - \alpha$$

$$g(t) = k(E \sin\omega t - B/2) \qquad \pi - \alpha < \omega t$$

The fundamental of the Fourier Series representation of the output is

$$A_1 \cos\omega t - B_1 \sin\omega t$$

where

$$A_1 = \frac{2}{\pi} \int_0^{\pi} g(t) \cos\omega t \, dt$$

$$B_1 = \frac{2}{\pi} \int_0^{\pi} g(t) \sin\omega t \, dt$$

Integrating and dividing by the input amplitude gives

$$A_1 = \frac{k}{\pi}\left[\frac{\pi}{2} - \sin^{-1}(1-B/E) + \frac{\sin\left(2\sin^{-1}(1-B/E)\right)}{2}\right]$$

$$= \frac{k}{\pi}\left[\frac{\pi}{2} + \beta + \frac{\sin 2\beta}{2}\right]$$

$$B_1 = \frac{-k}{\pi}\left[(B/E)^2 - (B/E)\right]$$

$$= \frac{-k}{\pi}\cos^2\beta \qquad\qquad \beta = \sin^{-1}(1-B/E)$$

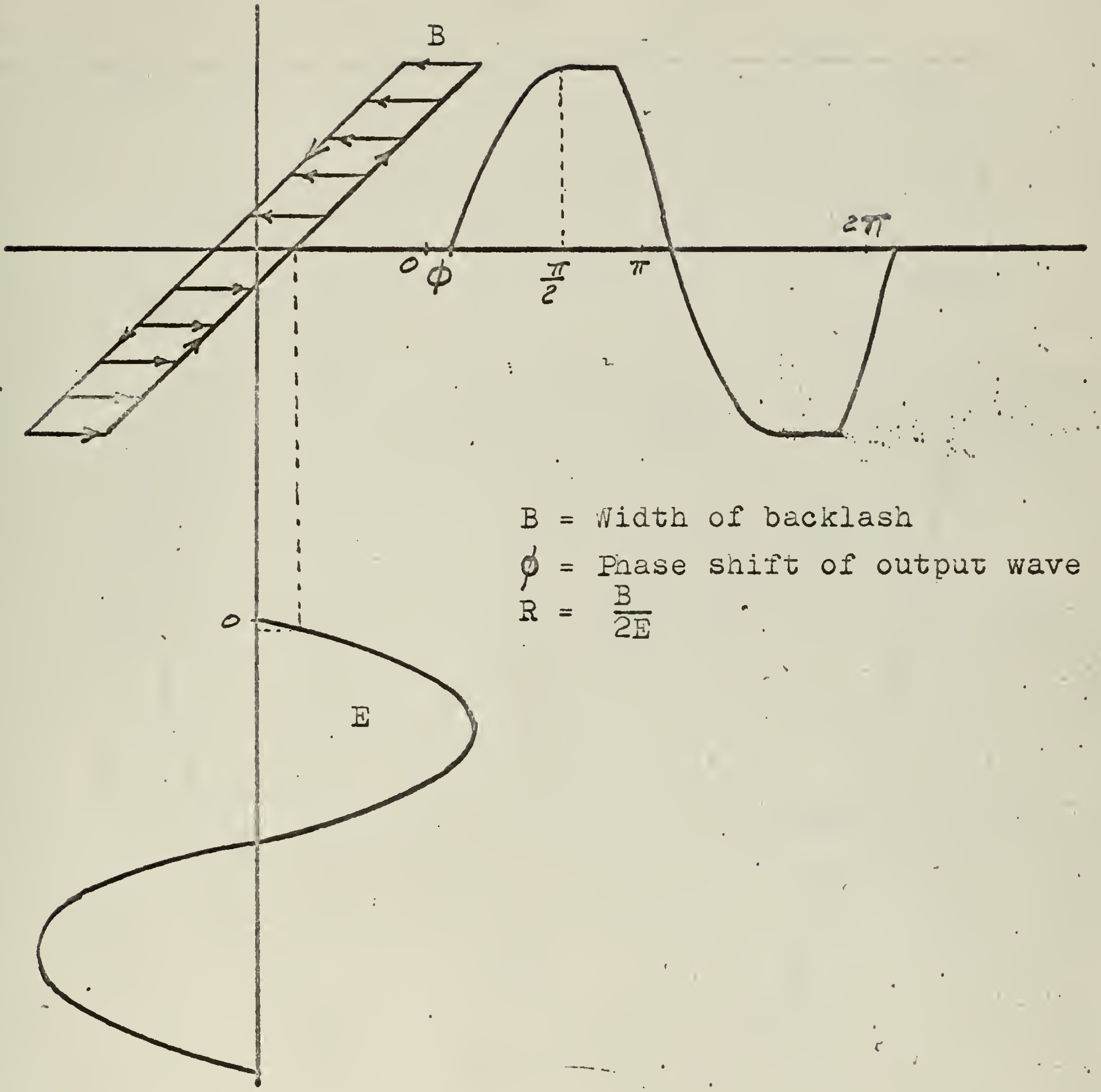
$$GD = A_1 - jB_1$$

$$= A_1{}^2 - B_1{}^2 \quad \angle \tan^{-1} B_1/A_1$$

Two simplifications may be made at this point. First of all, the slope (k) of the linear portion of the backlash loop appears as an external multiplier. It may therefore be removed and combined with any other gain factors in the system. Secondly, it may be noted that the ratio B/E has been preserved in the above equations. The describing function may be computed and plotted as a function of this ratio. For simplification, the inverse of this ratio,

$$R = B/2E$$

was used in the computation of the data.



B = Width of backlash

ϕ = Phase shift of output wave

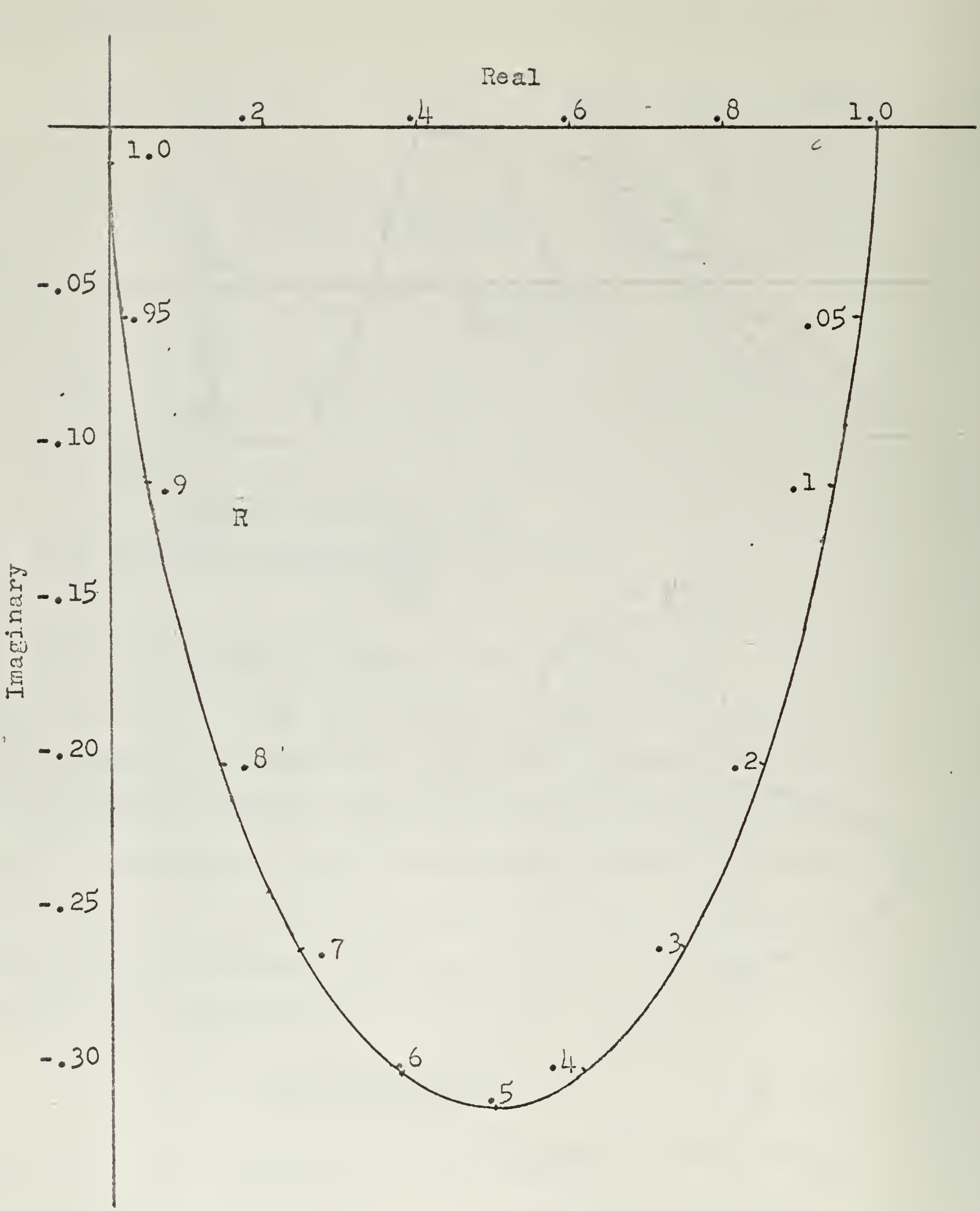
R = $\frac{B}{2E}$

$$X = \frac{1}{2} + \frac{1}{\pi}\sin^{-1}(1-2R) + \frac{\sin(2\sin^{-1}(1-2R))}{2}$$

$$Y = \frac{-1}{\pi}\cos^2(\sin^{-1}(1-2R))$$

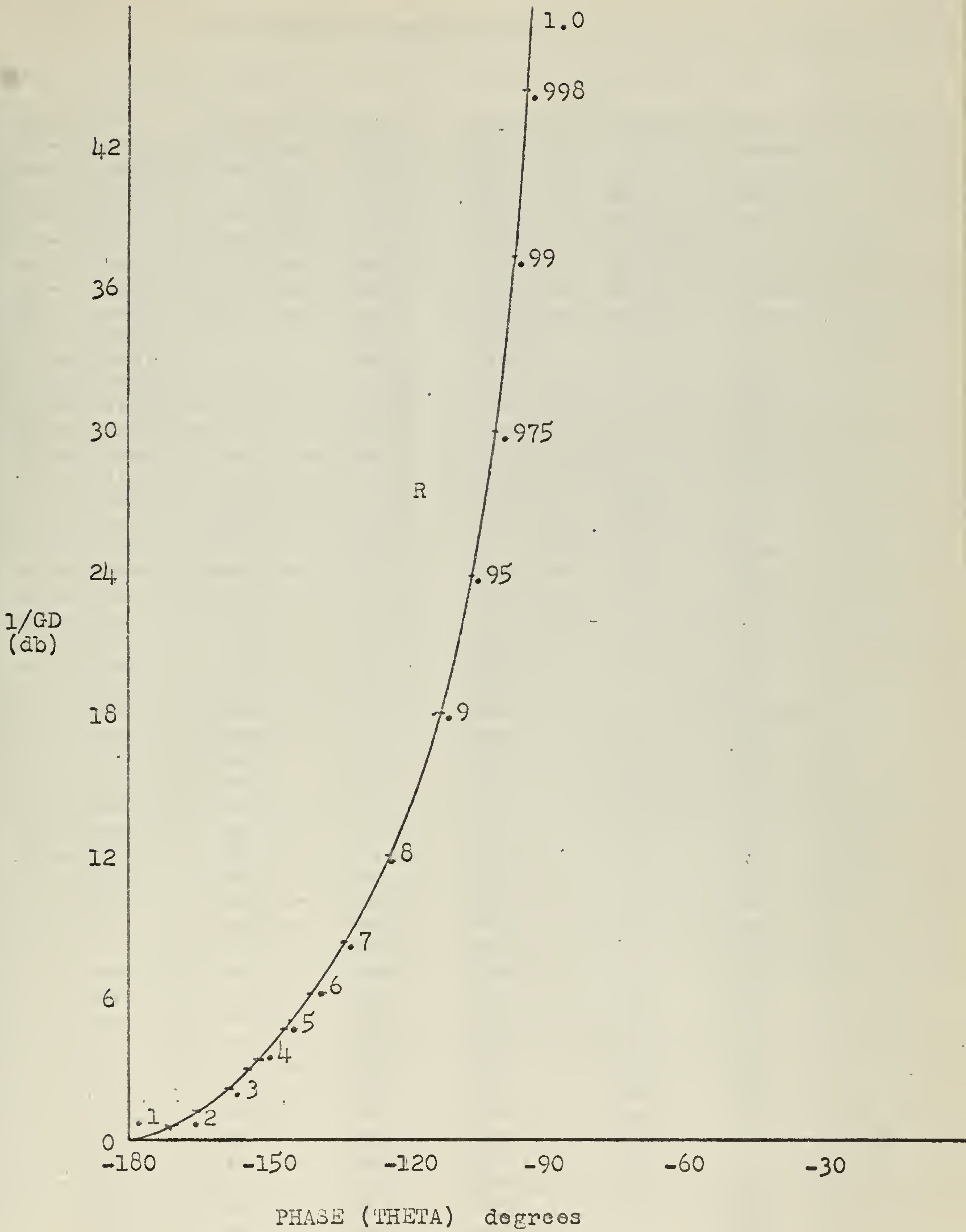
$$GD = \sqrt{X^2 + Y^2} \quad \tan^{-1}\frac{Y}{X}$$

FRICTION CONTROLLED BACKLASH
Figure XI-1



FRICTION CONTROLLED BACKLASH

REAL AND IMAGINARY COMPONENTS
Figure XI-2



FRICTION CONTROLLED BACKLASH

MAGNITUDE(DB) AND PHASE

Figure XI-3

FRICTION CONTROLLED BACKLASH

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
1.0000	.0000	-.0000	.0000	-90.00	*	-90.00
.9980	.0002	-.0025	.0025	-86.56	51.8829	-93.44
.9960	.0004	-.0051	.0051	-85.15	45.8643	-94.85
.9940	.0008	-.0076	.0076	-84.07	42.3445	-95.93
.9920	.0012	-.0101	.0102	-83.15	39.8476	-96.85
.9900	.0017	-.0126	.0127	-82.35	37.9114	-97.65
.9880	.0022	-.0151	.0153	-81.62	36.3297	-98.38
.9860	.0028	-.0176	.0178	-80.94	34.9928	-99.06
.9840	.0034	-.0200	.0203	-80.32	33.8349	-99.68
.9820	.0041	-.0225	.0229	-79.73	32.8138	-100.27
.9800	.0048	-.0250	.0254	-79.17	31.9006	-100.83
.9780	.0055	-.0274	.0279	-78.64	31.0747	-101.36
.9760	.0063	-.0298	.0305	-78.13	30.3209	-101.87
.9740	.0071	-.0322	.0330	-77.65	29.6276	-102.35
.9720	.0079	-.0347	.0355	-77.18	28.9859	-102.82
.9700	.0087	-.0371	.0381	-76.72	28.3886	-103.28
.9680	.0096	-.0394	.0406	-76.29	27.8301	-103.71
.9660	.0105	-.0418	.0431	-75.86	27.3055	-104.14
.9640	.0115	-.0442	.0457	-75.45	26.8110	-104.55
.9620	.0124	-.0465	.0482	-75.05	26.3434	-104.95
.9600	.0134	-.0489	.0507	-74.65	25.8998	-105.35
.9580	.0144	-.0512	.0532	-74.27	25.4780	-105.73
.9560	.0155	-.0536	.0557	-73.90	25.0760	-106.10
.9540	.0165	-.0559	.0583	-73.53	24.6919	-106.47
.9520	.0176	-.0582	.0608	-73.17	24.3242	-106.83
.9500	.0187	-.0605	.0633	-72.82	23.9716	-107.18
.9480	.0198	-.0628	.0658	-72.48	23.6330	-107.52
.9460	.0210	-.0650	.0683	-72.14	23.3072	-107.86
.9440	.0221	-.0673	.0708	-71.81	22.9933	-108.19
.9420	.0233	-.0696	.0734	-71.48	22.6906	-108.52
.9400	.0245	-.0718	.0759	-71.16	22.3981	-108.84
.9380	.0257	-.0740	.0784	-70.85	22.1154	-109.15
.9360	.0270	-.0763	.0809	-70.54	21.8416	-109.46
.9340	.0282	-.0785	.0834	-70.23	21.5764	-109.77
.9320	.0295	-.0807	.0859	-69.93	21.3191	-110.07
.9300	.0308	-.0829	.0884	-69.63	21.0694	-110.37
.9280	.0321	-.0851	.0909	-69.34	20.8268	-110.66
.9260	.0334	-.0872	.0934	-69.05	20.5908	-110.95
.9240	.0347	-.0894	.0959	-68.76	20.3612	-111.24
.9220	.0361	-.0916	.0984	-68.48	20.1377	-111.52
.9200	.0375	-.0937	.1009	-68.20	19.9198	-111.80
.9180	.0389	-.0958	.1034	-67.93	19.7074	-112.07
.9160	.0403	-.0980	.1059	-67.65	19.5002	-112.35
.9140	.0417	-.1001	.1084	-67.38	19.2979	-112.62
.9120	.0431	-.1022	.1109	-67.12	19.1003	-112.88
.9100	.0446	-.1043	.1134	-66.85	18.9072	-113.15
.9080	.0460	-.1064	.1159	-66.59	18.7183	-113.41
.9060	.0475	-.1084	.1184	-66.33	18.5336	-113.67
.9040	.0490	-.1105	.1209	-66.08	18.3529	-113.92
.9020	.0505	-.1125	.1234	-65.82	18.1759	-114.18

FRICTION CONTROLLED BACKLASH

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.9000	.0520	-.1146	.1259	-65.57	18.0025	-114.43
.8980	.0536	-.1166	.1283	-65.32	17.8326	-114.68
.8960	.0551	-.1186	.1308	-65.08	17.6660	-114.92
.8940	.0567	-.1207	.1333	-64.83	17.5027	-115.17
.8920	.0583	-.1227	.1358	-64.59	17.3425	-115.41
.8900	.0599	-.1246	.1383	-64.35	17.1852	-115.65
.8880	.0615	-.1266	.1408	-64.11	17.0308	-115.89
.8860	.0631	-.1286	.1432	-63.88	16.8792	-116.12
.8840	.0647	-.1306	.1457	-63.64	16.7303	-116.36
.8820	.0663	-.1325	.1482	-63.41	16.5839	-116.59
.8800	.0680	-.1345	.1507	-63.18	16.4401	-116.82
.8780	.0696	-.1364	.1531	-62.95	16.2987	-117.05
.8760	.0713	-.1383	.1556	-62.73	16.1596	-117.27
.8740	.0730	-.1402	.1581	-62.50	16.0227	-117.50
.8720	.0747	-.1421	.1605	-62.28	15.8881	-117.72
.8700	.0764	-.1440	.1630	-62.05	15.7556	-117.95
.8680	.0781	-.1459	.1655	-61.83	15.6251	-118.17
.8660	.0798	-.1478	.1679	-61.61	15.4967	-118.39
.8640	.0816	-.1496	.1704	-61.40	15.3702	-118.60
.8620	.0833	-.1515	.1729	-61.18	15.2456	-118.82
.8600	.0851	-.1533	.1753	-60.97	15.1228	-119.03
.8580	.0869	-.1551	.1778	-60.75	15.0017	-119.25
.8560	.0887	-.1569	.1803	-60.54	14.8824	-119.46
.8540	.0904	-.1588	.1827	-60.33	14.7648	-119.67
.8520	.0922	-.1606	.1852	-60.12	14.6488	-119.88
.8500	.0941	-.1623	.1876	-59.91	14.5344	-120.09
.8480	.0959	-.1641	.1901	-59.70	14.4216	-120.30
.8460	.0977	-.1659	.1925	-59.50	14.3103	-120.50
.8440	.0996	-.1676	.1950	-59.29	14.2004	-120.71
.8420	.1014	-.1694	.1974	-59.09	14.0920	-120.91
.8400	.1033	-.1711	.1999	-58.89	13.9849	-121.11
.8380	.1051	-.1728	.2023	-58.69	13.8793	-121.31
.8360	.1070	-.1746	.2048	-58.49	13.7749	-121.51
.8340	.1089	-.1763	.2072	-58.29	13.6719	-121.71
.8320	.1108	-.1780	.2097	-58.09	13.5701	-121.91
.8300	.1127	-.1797	.2121	-57.89	13.4695	-122.11
.8280	.1146	-.1813	.2145	-57.70	13.3702	-122.30
.8260	.1166	-.1830	.2170	-57.50	13.2720	-122.50
.8240	.1185	-.1846	.2194	-57.31	13.1750	-122.69
.8220	.1205	-.1863	.2218	-57.11	13.0791	-122.89
.8200	.1224	-.1879	.2243	-56.92	12.9843	-123.08
.8180	.1244	-.1896	.2267	-56.73	12.8906	-123.27
.8160	.1263	-.1912	.2291	-56.54	12.7979	-123.46
.8140	.1283	-.1928	.2316	-56.35	12.7063	-123.65
.8120	.1303	-.1944	.2340	-56.16	12.6157	-123.84
.8100	.1323	-.1960	.2364	-55.98	12.5261	-124.02
.8080	.1343	-.1975	.2389	-55.79	12.4374	-124.21
.8060	.1363	-.1991	.2413	-55.60	12.3497	-124.40
.8040	.1383	-.2006	.2437	-55.42	12.2629	-124.58
.8020	.1403	-.2022	.2461	-55.23	12.1770	-124.77

FRICTION CONTROLLED BACKLASH

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.8000	.1424	-.2037	.2485	-55.05	12.0920	-124.95
.7980	.1444	-.2052	.2510	-54.87	12.0079	-125.13
.7960	.1465	-.2068	.2534	-54.69	11.9246	-125.31
.7940	.1485	-.2083	.2558	-54.50	11.8422	-125.50
.7920	.1506	-.2097	.2582	-54.32	11.7606	-125.68
.7900	.1527	-.2112	.2606	-54.14	11.6798	-125.86
.7880	.1547	-.2127	.2630	-53.96	11.5998	-126.04
.7860	.1568	-.2142	.2654	-53.79	11.5206	-126.21
.7840	.1589	-.2156	.2679	-53.61	11.4422	-126.39
.7820	.1610	-.2171	.2703	-53.43	11.3645	-126.57
.7800	.1631	-.2185	.2727	-53.26	11.2875	-126.74
.7780	.1652	-.2199	.2751	-53.08	11.2112	-126.92
.7760	.1674	-.2213	.2775	-52.90	11.1357	-127.10
.7740	.1695	-.2227	.2799	-52.73	11.0609	-127.27
.7720	.1716	-.2241	.2823	-52.56	10.9867	-127.44
.7700	.1738	-.2255	.2847	-52.38	10.9132	-127.62
.7680	.1759	-.2269	.2871	-52.21	10.8404	-127.79
.7660	.1781	-.2282	.2895	-52.04	10.7682	-127.96
.7640	.1802	-.2296	.2919	-51.87	10.6967	-128.13
.7620	.1824	-.2309	.2942	-51.70	10.6258	-128.30
.7600	.1846	-.2322	.2966	-51.53	10.5555	-128.47
.7580	.1867	-.2336	.2990	-51.36	10.4858	-128.64
.7560	.1889	-.2349	.3014	-51.19	10.4167	-128.81
.7540	.1911	-.2362	.3038	-51.02	10.3483	-128.98
.7520	.1933	-.2375	.3062	-50.85	10.2803	-129.15
.7500	.1955	-.2387	.3086	-50.69	10.2130	-129.31
.7480	.1977	-.2400	.3109	-50.52	10.1462	-129.48
.7460	.1999	-.2413	.3133	-50.35	10.0800	-129.65
.7440	.2021	-.2425	.3157	-50.19	10.0143	-129.81
.7420	.2044	-.2437	.3181	-50.02	9.9492	-129.98
.7400	.2066	-.2450	.3205	-49.86	9.8845	-130.14
.7380	.2088	-.2462	.3228	-49.69	9.8204	-130.31
.7360	.2111	-.2474	.3252	-49.53	9.7568	-130.47
.7340	.2133	-.2486	.3276	-49.37	9.6937	-130.63
.7320	.2156	-.2498	.3299	-49.20	9.6312	-130.80
.7300	.2178	-.2510	.3323	-49.04	9.5690	-130.96
.7280	.2201	-.2521	.3347	-48.88	9.5074	-131.12
.7260	.2224	-.2533	.3370	-48.72	9.4463	-131.28
.7240	.2246	-.2544	.3394	-48.56	9.3856	-131.44
.7220	.2269	-.2556	.3418	-48.40	9.3254	-131.60
.7200	.2292	-.2567	.3441	-48.24	9.2656	-131.76
.7180	.2315	-.2578	.3465	-48.08	9.2063	-131.92
.7160	.2338	-.2589	.3488	-47.92	9.1474	-132.08
.7140	.2361	-.2600	.3512	-47.76	9.0890	-132.24
.7120	.2384	-.2611	.3535	-47.60	9.0310	-132.40
.7100	.2407	-.2622	.3559	-47.44	8.9734	-132.56
.7080	.2430	-.2632	.3583	-47.29	8.9162	-132.71
.7060	.2453	-.2643	.3606	-47.13	8.8595	-132.87
.7040	.2477	-.2653	.3629	-46.97	8.8031	-133.03
.7020	.2500	-.2664	.3653	-46.82	8.7472	-133.18

FRICTION CONTROLLED BACKLASH

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.7000	.2523	-.2674	.3676	-46.66	8.6917	-133.34
.6980	.2547	-.2684	.3700	-46.50	8.6365	-133.50
.6960	.2570	-.2694	.3723	-46.35	8.5817	-133.65
.6940	.2593	-.2704	.3747	-46.20	8.5274	-133.80
.6920	.2617	-.2714	.3770	-46.04	8.4734	-133.96
.6900	.2640	-.2723	.3793	-45.89	8.4197	-134.11
.6880	.2664	-.2733	.3817	-45.73	8.3664	-134.27
.6860	.2688	-.2743	.3840	-45.58	8.3135	-134.42
.6840	.2711	-.2752	.3863	-45.43	8.2610	-134.57
.6820	.2735	-.2761	.3887	-45.28	8.2088	-134.72
.6800	.2759	-.2771	.3910	-45.12	8.1570	-134.88
.6780	.2782	-.2780	.3933	-44.97	8.1055	-135.03
.6760	.2806	-.2789	.3956	-44.82	8.0543	-135.18
.6740	.2830	-.2798	.3979	-44.67	8.0035	-135.33
.6720	.2854	-.2806	.4003	-44.52	7.9530	-135.48
.6700	.2878	-.2815	.4026	-44.37	7.9028	-135.63
.6680	.2902	-.2824	.4049	-44.22	7.8530	-135.78
.6660	.2926	-.2832	.4072	-44.07	7.8035	-135.93
.6640	.2950	-.2841	.4095	-43.92	7.7543	-136.08
.6620	.2974	-.2849	.4118	-43.77	7.7054	-136.23
.6600	.2998	-.2857	.4142	-43.62	7.6568	-136.38
.6580	.3022	-.2865	.4165	-43.47	7.6086	-136.53
.6560	.3046	-.2873	.4188	-43.32	7.5606	-136.68
.6540	.3071	-.2881	.4211	-43.18	7.5129	-136.82
.6520	.3095	-.2889	.4234	-43.03	7.4656	-136.97
.6500	.3119	-.2897	.4257	-42.88	7.4185	-137.12
.6480	.3144	-.2904	.4280	-42.73	7.3717	-137.27
.6460	.3168	-.2912	.4303	-42.59	7.3252	-137.41
.6440	.3192	-.2919	.4326	-42.44	7.2790	-137.56
.6420	.3217	-.2926	.4349	-42.29	7.2331	-137.71
.6400	.3241	-.2934	.4371	-42.15	7.1874	-137.85
.6380	.3266	-.2941	.4394	-42.00	7.1420	-138.00
.6360	.3290	-.2948	.4417	-41.86	7.0969	-138.14
.6340	.3315	-.2954	.4440	-41.71	7.0521	-138.29
.6320	.3339	-.2961	.4463	-41.57	7.0075	-138.43
.6300	.3364	-.2968	.4486	-41.42	6.9632	-138.58
.6280	.3388	-.2974	.4509	-41.28	6.9191	-138.72
.6260	.3413	-.2981	.4531	-41.14	6.8753	-138.86
.6240	.3438	-.2987	.4554	-40.99	6.8318	-139.01
.6220	.3462	-.2994	.4577	-40.85	6.7885	-139.15
.6200	.3487	-.3000	.4600	-40.71	6.7455	-139.29
.6180	.3512	-.3006	.4622	-40.56	6.7027	-139.44
.6160	.3536	-.3012	.4645	-40.42	6.6601	-139.58
.6140	.3561	-.3018	.4668	-40.28	6.6178	-139.72
.6120	.3586	-.3023	.4690	-40.13	6.5757	-139.87
.6100	.3611	-.3029	.4713	-39.99	6.5339	-140.01
.6080	.3636	-.3035	.4736	-39.85	6.4923	-140.15
.6060	.3661	-.3040	.4758	-39.71	6.4510	-140.29
.6040	.3685	-.3045	.4781	-39.57	6.4098	-140.43
.6020	.3710	-.3051	.4803	-39.43	6.3689	-140.57

FRICTION CONTROLLED BACKLASH

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.6000	.3735	-.3056	.4826	-39.29	6.3283	-140.71
.5980	.3760	-.3061	.4849	-39.15	6.2878	-140.85
.5960	.3785	-.3066	.4871	-39.00	6.2476	-141.00
.5940	.3810	-.3071	.4894	-38.86	6.2076	-141.14
.5920	.3835	-.3075	.4916	-38.72	6.1678	-141.28
.5900	.3860	-.3080	.4938	-38.58	6.1282	-141.42
.5880	.3885	-.3084	.4961	-38.45	6.0889	-141.55
.5860	.3910	-.3089	.4983	-38.31	6.0497	-141.69
.5840	.3936	-.3093	.5006	-38.17	6.0108	-141.83
.5820	.3961	-.3097	.5028	-38.03	5.9720	-141.97
.5800	.3986	-.3102	.5050	-37.89	5.9335	-142.11
.5780	.4011	-.3106	.5073	-37.75	5.8952	-142.25
.5760	.4036	-.3110	.5095	-37.61	5.8571	-142.39
.5740	.4061	-.3113	.5117	-37.47	5.8192	-142.53
.5720	.4086	-.3117	.5140	-37.34	5.7814	-142.66
.5700	.4112	-.3121	.5162	-37.20	5.7439	-142.80
.5680	.4137	-.3124	.5184	-37.06	5.7066	-142.94
.5660	.4162	-.3128	.5206	-36.92	5.6695	-143.08
.5640	.4187	-.3131	.5228	-36.79	5.6325	-143.21
.5620	.4213	-.3134	.5251	-36.65	5.5958	-143.35
.5600	.4238	-.3137	.5273	-36.51	5.5592	-143.49
.5580	.4263	-.3140	.5295	-36.38	5.5228	-143.62
.5560	.4288	-.3143	.5317	-36.24	5.4867	-143.76
.5540	.4314	-.3146	.5339	-36.10	5.4507	-143.90
.5520	.4339	-.3149	.5361	-35.97	5.4148	-144.03
.5500	.4364	-.3151	.5383	-35.83	5.3792	-144.17
.5480	.4390	-.3154	.5405	-35.69	5.3437	-144.31
.5460	.4415	-.3156	.5427	-35.56	5.3084	-144.44
.5440	.4440	-.3158	.5449	-35.42	5.2733	-144.58
.5420	.4466	-.3161	.5471	-35.29	5.2384	-144.71
.5400	.4491	-.3163	.5493	-35.15	5.2037	-144.85
.5380	.4517	-.3165	.5515	-35.02	5.1691	-144.98
.5360	.4542	-.3167	.5537	-34.88	5.1347	-145.12
.5340	.4567	-.3168	.5559	-34.75	5.1004	-145.25
.5320	.4593	-.3170	.5581	-34.61	5.0663	-145.39
.5300	.4618	-.3172	.5602	-34.48	5.0324	-145.52
.5280	.4644	-.3173	.5624	-34.35	4.9987	-145.65
.5260	.4669	-.3174	.5646	-34.21	4.9651	-145.79
.5240	.4695	-.3176	.5668	-34.08	4.9317	-145.92
.5220	.4720	-.3177	.5690	-33.94	4.8984	-146.06
.5200	.4745	-.3178	.5711	-33.81	4.8653	-146.19
.5180	.4771	-.3179	.5733	-33.68	4.8324	-146.32
.5160	.4796	-.3180	.5755	-33.54	4.7996	-146.46
.5140	.4822	-.3181	.5776	-33.41	4.7670	-146.59
.5120	.4847	-.3181	.5798	-33.28	4.7345	-146.72
.5100	.4873	-.3182	.5820	-33.14	4.7022	-146.86
.5080	.4898	-.3182	.5841	-33.01	4.6701	-146.99
.5060	.4924	-.3183	.5863	-32.88	4.6381	-147.12
.5040	.4949	-.3183	.5884	-32.75	4.6062	-147.25
.5020	.4975	-.3183	.5906	-32.61	4.5745	-147.39

FRICTION CONTROLLED BACKLASH

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.5000	.5000	-.3183	.5927	-32.48	4.5430	-147.52
.4980	.5025	-.3183	.5949	-32.35	4.5116	-147.65
.4960	.5051	-.3183	.5970	-32.22	4.4803	-147.78
.4940	.5076	-.3183	.5992	-32.09	4.4492	-147.91
.4920	.5102	-.3182	.6013	-31.95	4.4182	-148.05
.4900	.5127	-.3182	.6034	-31.82	4.3874	-148.18
.4880	.5153	-.3181	.6056	-31.69	4.3567	-148.31
.4860	.5178	-.3181	.6077	-31.56	4.3262	-148.44
.4840	.5204	-.3180	.6098	-31.43	4.2958	-148.57
.4820	.5229	-.3179	.6120	-31.30	4.2655	-148.70
.4800	.5255	-.3178	.6141	-31.17	4.2354	-148.83
.4780	.5280	-.3177	.6162	-31.03	4.2054	-148.97
.4760	.5305	-.3176	.6183	-30.90	4.1756	-149.10
.4740	.5331	-.3174	.6204	-30.77	4.1459	-149.23
.4720	.5356	-.3173	.6226	-30.64	4.1163	-149.36
.4700	.5382	-.3172	.6247	-30.51	4.0869	-149.49
.4680	.5407	-.3170	.6268	-30.38	4.0576	-149.62
.4660	.5433	-.3168	.6289	-30.25	4.0284	-149.75
.4640	.5458	-.3167	.6310	-30.12	3.9993	-149.88
.4620	.5483	-.3165	.6331	-29.99	3.9704	-150.01
.4600	.5509	-.3163	.6352	-29.86	3.9417	-150.14
.4580	.5534	-.3161	.6373	-29.73	3.9130	-150.27
.4560	.5560	-.3158	.6394	-29.60	3.8845	-150.40
.4540	.5585	-.3156	.6415	-29.47	3.8561	-150.53
.4520	.5610	-.3154	.6436	-29.34	3.8278	-150.66
.4500	.5636	-.3151	.6457	-29.21	3.7997	-150.79
.4480	.5661	-.3149	.6478	-29.08	3.7717	-150.92
.4460	.5686	-.3146	.6498	-28.95	3.7438	-151.05
.4440	.5712	-.3143	.6519	-28.82	3.7160	-151.18
.4420	.5737	-.3140	.6540	-28.70	3.6884	-151.30
.4400	.5762	-.3137	.6561	-28.57	3.6609	-151.43
.4380	.5787	-.3134	.6582	-28.44	3.6335	-151.56
.4360	.5813	-.3131	.6602	-28.31	3.6062	-151.69
.4340	.5838	-.3128	.6623	-28.18	3.5790	-151.82
.4320	.5863	-.3124	.6644	-28.05	3.5520	-151.95
.4300	.5888	-.3121	.6664	-27.92	3.5251	-152.08
.4280	.5914	-.3117	.6685	-27.79	3.4983	-152.21
.4260	.5939	-.3113	.6705	-27.67	3.4716	-152.33
.4240	.5964	-.3110	.6726	-27.54	3.4450	-152.46
.4220	.5989	-.3106	.6746	-27.41	3.4185	-152.59
.4200	.6014	-.3102	.6767	-27.28	3.3922	-152.72
.4180	.6039	-.3097	.6787	-27.15	3.3660	-152.85
.4160	.6064	-.3093	.6808	-27.02	3.3399	-152.98
.4140	.6090	-.3089	.6828	-26.90	3.3139	-153.10
.4120	.6115	-.3084	.6849	-26.77	3.2880	-153.23
.4100	.6140	-.3080	.6869	-26.64	3.2622	-153.36
.4080	.6165	-.3075	.6889	-26.51	3.2366	-153.49
.4060	.6190	-.3071	.6910	-26.38	3.2110	-153.62
.4040	.6215	-.3066	.6930	-26.26	3.1856	-153.74
.4020	.6240	-.3061	.6950	-26.13	3.1603	-153.87

FRICTION CONTROLLED BACKLASH

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.4000	.6265	-.3056	.6970	-26.00	3.1351	-154.00
.3980	.6290	-.3051	.6990	-25.87	3.1099	-154.13
.3960	.6315	-.3045	.7011	-25.75	3.0849	-154.25
.3940	.6339	-.3040	.7031	-25.62	3.0601	-154.38
.3920	.6364	-.3035	.7051	-25.49	3.0353	-154.51
.3900	.6389	-.3029	.7071	-25.37	3.0106	-154.63
.3880	.6414	-.3023	.7091	-25.24	2.9860	-154.76
.3860	.6439	-.3018	.7111	-25.11	2.9616	-154.89
.3840	.6464	-.3012	.7131	-24.98	2.9372	-155.02
.3820	.6488	-.3006	.7151	-24.86	2.9129	-155.14
.3800	.6513	-.3000	.7171	-24.73	2.8888	-155.27
.3780	.6538	-.2994	.7191	-24.60	2.8647	-155.40
.3760	.6562	-.2987	.7210	-24.48	2.8408	-155.52
.3740	.6587	-.2981	.7230	-24.35	2.8169	-155.65
.3720	.6612	-.2974	.7250	-24.22	2.7932	-155.78
.3700	.6636	-.2968	.7270	-24.10	2.7696	-155.90
.3680	.6661	-.2961	.7290	-23.97	2.7460	-156.03
.3660	.6685	-.2954	.7309	-23.84	2.7226	-156.16
.3640	.6710	-.2948	.7329	-23.72	2.6992	-156.28
.3620	.6734	-.2941	.7349	-23.59	2.6760	-156.41
.3600	.6759	-.2934	.7368	-23.46	2.6529	-156.54
.3580	.6783	-.2926	.7388	-23.34	2.6298	-156.66
.3560	.6808	-.2919	.7407	-23.21	2.6069	-156.79
.3540	.6832	-.2912	.7427	-23.08	2.5840	-156.92
.3520	.6856	-.2904	.7446	-22.96	2.5613	-157.04
.3500	.6881	-.2897	.7466	-22.83	2.5387	-157.17
.3480	.6905	-.2889	.7485	-22.70	2.5161	-157.30
.3460	.6929	-.2881	.7504	-22.58	2.4936	-157.42
.3440	.6954	-.2873	.7524	-22.45	2.4713	-157.55
.3420	.6978	-.2865	.7543	-22.32	2.4490	-157.68
.3400	.7002	-.2857	.7562	-22.20	2.4269	-157.80
.3380	.7026	-.2849	.7582	-22.07	2.4048	-157.93
.3360	.7050	-.2841	.7601	-21.95	2.3828	-158.05
.3340	.7074	-.2832	.7620	-21.82	2.3609	-158.18
.3320	.7098	-.2824	.7639	-21.69	2.3391	-158.31
.3300	.7122	-.2815	.7658	-21.57	2.3174	-158.43
.3280	.7146	-.2806	.7677	-21.44	2.2958	-158.56
.3260	.7170	-.2798	.7696	-21.32	2.2743	-158.68
.3240	.7194	-.2789	.7715	-21.19	2.2529	-158.81
.3220	.7218	-.2780	.7734	-21.06	2.2316	-158.94
.3200	.7241	-.2771	.7753	-20.94	2.2103	-159.06
.3180	.7265	-.2761	.7772	-20.81	2.1892	-159.19
.3160	.7289	-.2752	.7791	-20.69	2.1681	-159.31
.3140	.7312	-.2743	.7810	-20.56	2.1472	-159.44
.3120	.7336	-.2733	.7829	-20.43	2.1263	-159.57
.3100	.7360	-.2723	.7847	-20.31	2.1055	-159.69
.3080	.7383	-.2714	.7866	-20.18	2.0849	-159.82
.3060	.7407	-.2704	.7885	-20.06	2.0643	-159.94
.3040	.7430	-.2694	.7903	-19.93	2.0437	-160.07
.3020	.7453	-.2684	.7922	-19.80	2.0233	-160.20

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                    FRICTION CONTROLLED BACKLASH
      R        REAL       IMAG        GD       PHASE   1/GD(DB)    THETA

   .3000      .7477     -.2674     .7941     -19.68     2.0030   -160.32
   .2980      .7500     -.2664     .7959     -19.55     1.9828   -160.45
   .2960      .7523     -.2653     .7978     -19.43     1.9626   -160.57
   .2940      .7547     -.2643     .7996     -19.30     1.9425   -160.70
   .2920      .7570     -.2632     .8014     -19.17     1.9226   -160.83
   .2900      .7593     -.2622     .8033     -19.05     1.9027   -160.95
   .2880      .7616     -.2611     .8051     -18.92     1.8829   -161.08
   .2860      .7639     -.2600     .8069     -18.80     1.8631   -161.20
   .2840      .7662     -.2589     .8088     -18.67     1.8435   -161.33
   .2820      .7685     -.2578     .8106     -18.54     1.8240   -161.46
   .2800      .7708     -.2567     .8124     -18.42     1.8045   -161.58
   .2780      .7731     -.2556     .8142     -18.29     1.7852   -161.71
   .2760      .7754     -.2544     .8160     -18.17     1.7659   -161.83
   .2740      .7776     -.2533     .8178     -18.04     1.7467   -161.96
   .2720      .7799     -.2521     .8196     -17.91     1.7276   -162.09
   .2700      .7822     -.2510     .8214     -17.79     1.7085   -162.21
   .2680      .7844     -.2498     .8232     -17.66     1.6896   -162.34
   .2660      .7867     -.2486     .8250     -17.54     1.6707   -162.46
   .2640      .7889     -.2474     .8268     -17.41     1.6520   -162.59
   .2620      .7912     -.2462     .8286     -17.28     1.6333   -162.72
   .2600      .7934     -.2450     .8304     -17.16     1.6147   -162.84
   .2580      .7956     -.2437     .8321     -17.03     1.5962   -162.97
   .2560      .7979     -.2425     .8339     -16.91     1.5778   -163.09
   .2540      .8001     -.2413     .8357     -16.78     1.5594   -163.22
   .2520      .8023     -.2400     .8374     -16.65     1.5412   -163.35
   .2500      .8045     -.2387     .8392     -16.53     1.5230   -163.47
   .2480      .8067     -.2375     .8409     -16.40     1.5049   -163.60
   .2460      .8089     -.2362     .8427     -16.28     1.4869   -163.72
   .2440      .8111     -.2349     .8444     -16.15     1.4690   -163.85
   .2420      .8133     -.2336     .8461     -16.02     1.4511   -163.98
   .2400      .8154     -.2322     .8479     -15.90     1.4334   -164.10
   .2380      .8176     -.2309     .8496     -15.77     1.4157   -164.23
   .2360      .8198     -.2296     .8513     -15.64     1.3981   -164.36
   .2340      .8219     -.2282     .8530     -15.52     1.3806   -164.48
   .2320      .8241     -.2269     .8548     -15.39     1.3632   -164.61
   .2300      .8262     -.2255     .8565     -15.26     1.3458   -164.74
   .2280      .8284     -.2241     .8582     -15.14     1.3286   -164.86
   .2260      .8305     -.2227     .8599     -15.01     1.3114   -164.99
   .2240      .8326     -.2213     .8616     -14.89     1.2943   -165.11
   .2220      .8348     -.2199     .8632     -14.76     1.2773   -165.24
   .2200      .8369     -.2185     .8649     -14.63     1.2604   -165.37
   .2180      .8390     -.2171     .8666     -14.51     1.2435   -165.49
   .2160      .8411     -.2156     .8683     -14.38     1.2268   -165.62
   .2140      .8432     -.2142     .8700     -14.25     1.2101   -165.75
   .2120      .8453     -.2127     .8716     -14.12     1.1935   -165.88
   .2100      .8473     -.2112     .8733     -14.00     1.1770   -166.00
   .2080      .8494     -.2097     .8749     -13.87     1.1606   -166.13
   .2060      .8515     -.2083     .8766     -13.74     1.1442   -166.26
   .2040      .8535     -.2068     .8782     -13.62     1.1280   -166.38
   .2020      .8556     -.2052     .8799     -13.49     1.1118   -166.51
```

FRICTION CONTROLLED BACKLASH

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.2000	.8576	-.2037	.8815	-13.36	1.0957	-166.64
.1980	.8597	-.2022	.8831	-13.24	1.0797	-166.76
.1960	.8617	-.2006	.8847	-13.11	1.0638	-166.89
.1940	.8637	-.1991	.8863	-12.98	1.0479	-167.02
.1920	.8657	-.1975	.8880	-12.85	1.0322	-167.15
.1900	.8677	-.1960	.8896	-12.73	1.0165	-167.27
.1880	.8697	-.1944	.8912	-12.60	1.0009	-167.40
.1860	.8717	-.1928	.8928	-12.47	.9854	-167.53
.1840	.8737	-.1912	.8943	-12.34	.9700	-167.66
.1820	.8756	-.1896	.8959	-12.21	.9546	-167.79
.1800	.8776	-.1879	.8975	-12.09	.9394	-167.91
.1780	.8795	-.1863	.8991	-11.96	.9242	-168.04
.1760	.8815	-.1846	.9006	-11.83	.9091	-168.17
.1740	.8834	-.1830	.9022	-11.70	.8941	-168.30
.1720	.8854	-.1813	.9037	-11.57	.8792	-168.43
.1700	.8873	-.1797	.9053	-11.45	.8644	-168.55
.1680	.8892	-.1780	.9068	-11.32	.8496	-168.68
.1660	.8911	-.1763	.9083	-11.19	.8350	-168.81
.1640	.8930	-.1746	.9099	-11.06	.8204	-168.94
.1620	.8949	-.1728	.9114	-10.93	.8059	-169.07
.1600	.8967	-.1711	.9129	-10.80	.7915	-169.20
.1580	.8986	-.1694	.9144	-10.68	.7772	-169.32
.1560	.9004	-.1676	.9159	-10.55	.7629	-169.45
.1540	.9023	-.1659	.9174	-10.42	.7488	-169.58
.1520	.9041	-.1641	.9189	-10.29	.7347	-169.71
.1500	.9059	-.1623	.9204	-10.16	.7208	-169.84
.1480	.9078	-.1606	.9218	-10.03	.7069	-169.97
.1460	.9096	-.1588	.9233	-9.90	.6931	-170.10
.1440	.9113	-.1569	.9248	-9.77	.6794	-170.23
.1420	.9131	-.1551	.9262	-9.64	.6658	-170.36
.1400	.9149	-.1533	.9277	-9.51	.6522	-170.49
.1380	.9167	-.1515	.9291	-9.38	.6388	-170.62
.1360	.9184	-.1496	.9305	-9.25	.6255	-170.75
.1340	.9202	-.1478	.9319	-9.12	.6122	-170.88
.1320	.9219	-.1459	.9334	-8.99	.5990	-171.01
.1300	.9236	-.1440	.9348	-8.86	.5860	-171.14
.1280	.9253	-.1421	.9362	-8.73	.5730	-171.27
.1260	.9270	-.1402	.9376	-8.60	.5601	-171.40
.1240	.9287	-.1383	.9389	-8.47	.5473	-171.53
.1220	.9304	-.1364	.9403	-8.34	.5346	-171.66
.1200	.9320	-.1345	.9417	-8.21	.5220	-171.79
.1180	.9337	-.1325	.9430	-8.08	.5095	-171.92
.1160	.9353	-.1306	.9444	-7.95	.4971	-172.05
.1140	.9369	-.1286	.9457	-7.82	.4847	-172.18
.1120	.9385	-.1266	.9471	-7.68	.4725	-172.32
.1100	.9401	-.1246	.9484	-7.55	.4604	-172.45
.1080	.9417	-.1227	.9497	-7.42	.4484	-172.58
.1060	.9433	-.1207	.9510	-7.29	.4364	-172.71
.1040	.9449	-.1186	.9523	-7.16	.4246	-172.84
.1020	.9464	-.1166	.9536	-7.02	.4129	-172.98

FRICTION CONTROLLED BACKLASH

R	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.1000	.9480	-.1146	.9549	-6.89	.4012	-173.11
.0980	.9495	-.1125	.9561	-6.76	.3897	-173.24
.0960	.9510	-.1105	.9574	-6.63	.3783	-173.37
.0940	.9525	-.1084	.9586	-6.49	.3670	-173.51
.0920	.9540	-.1064	.9599	-6.36	.3558	-173.64
.0900	.9554	-.1043	.9611	-6.23	.3447	-173.77
.0880	.9569	-.1022	.9623	-6.10	.3337	-173.90
.0860	.9583	-.1001	.9635	-5.96	.3228	-174.04
.0840	.9597	-.0980	.9647	-5.83	.3120	-174.17
.0820	.9611	-.0958	.9659	-5.69	.3014	-174.31
.0800	.9625	-.0937	.9671	-5.56	.2908	-174.44
.0780	.9639	-.0916	.9682	-5.43	.2804	-174.57
.0760	.9653	-.0894	.9694	-5.29	.2701	-174.71
.0740	.9666	-.0872	.9705	-5.16	.2599	-174.84
.0720	.9679	-.0851	.9717	-5.02	.2498	-174.98
.0700	.9692	-.0829	.9728	-4.89	.2398	-175.11
.0680	.9705	-.0807	.9739	-4.75	.2300	-175.25
.0660	.9718	-.0785	.9750	-4.62	.2203	-175.38
.0640	.9730	-.0763	.9760	-4.48	.2107	-175.52
.0620	.9743	-.0740	.9771	-4.35	.2013	-175.65
.0600	.9755	-.0718	.9781	-4.21	.1920	-175.79
.0580	.9767	-.0696	.9792	-4.07	.1828	-175.93
.0560	.9779	-.0673	.9802	-3.94	.1737	-176.06
.0540	.9790	-.0650	.9812	-3.80	.1648	-176.20
.0520	.9802	-.0628	.9822	-3.66	.1561	-176.34
.0500	.9813	-.0605	.9832	-3.53	.1474	-176.47
.0480	.9824	-.0582	.9841	-3.39	.1390	-176.61
.0460	.9835	-.0559	.9851	-3.25	.1307	-176.75
.0440	.9845	-.0536	.9860	-3.11	.1225	-176.89
.0420	.9856	-.0512	.9869	-2.98	.1145	-177.02
.0400	.9866	-.0489	.9878	-2.84	.1067	-177.16
.0380	.9876	-.0465	.9887	-2.70	.0990	-177.30
.0360	.9885	-.0442	.9895	-2.56	.0915	-177.44
.0340	.9895	-.0418	.9903	-2.42	.0842	-177.58
.0320	.9904	-.0394	.9912	-2.28	.0771	-177.72
.0300	.9913	-.0371	.9919	-2.14	.0702	-177.86
.0280	.9921	-.0347	.9927	-2.00	.0635	-178.00
.0260	.9929	-.0322	.9935	-1.86	.0570	-178.14
.0240	.9937	-.0298	.9942	-1.72	.0507	-178.28
.0220	.9945	-.0274	.9949	-1.58	.0446	-178.42
.0200	.9952	-.0250	.9955	-1.44	.0388	-178.56
.0180	.9959	-.0225	.9962	-1.29	.0333	-178.71
.0160	.9966	-.0200	.9968	-1.15	.0280	-178.85
.0140	.9972	-.0176	.9974	-1.01	.0230	-178.99
.0120	.9978	-.0151	.9979	-.87	.0184	-179.13
.0100	.9983	-.0126	.9984	-.72	.0140	-179.28
.0080	.9988	-.0101	.9988	-.58	.0101	-179.42
.0060	.9992	-.0076	.9992	-.44	.0066	-179.56
.0040	.9996	-.0051	.9996	-.29	.0036	-179.71
.0020	.9998	-.0025	.9999	-.15	.0013	-179.85

APPENDIX XII

Inertia Controlled Backlash

Brearley[4] developed the describing function for the backlash case where the inertia of the output member was much greater than the input member, and where friction could be ignored. Inertia controlled backlash is common in antenna systems, gun mounts, missile launchers, etc.

Figure XII-1 shows the physical model for inertia controlled backlash. Figure XII-2 gives a graphical representation of the displacement of the input and output members. The variable R is defined as:

$$R = \frac{B}{2E} \qquad \text{Where } B = \text{width of backlash}$$

$$E = \text{amplitude of input sine wave}$$

Then for $R > \frac{1}{\pi}$

$$\operatorname{Re}(GD) = X = \frac{1}{\pi}\left[(2 - \sin\theta_1)\cos\theta_1 + \left(2\theta_1 + \pi - \frac{2}{R}\right)\sin\theta_1 \right.$$
$$\left. \frac{\pi}{2} - \theta_1 \right]$$

$$\operatorname{Im}(GD) = Y = \frac{1}{\pi}\left[\left(2\theta_1 + \pi - \frac{2}{R}\right)\cos\theta_1 - 2\sin\theta_1 - 3 + \sin^2\theta_1 \right]$$

where

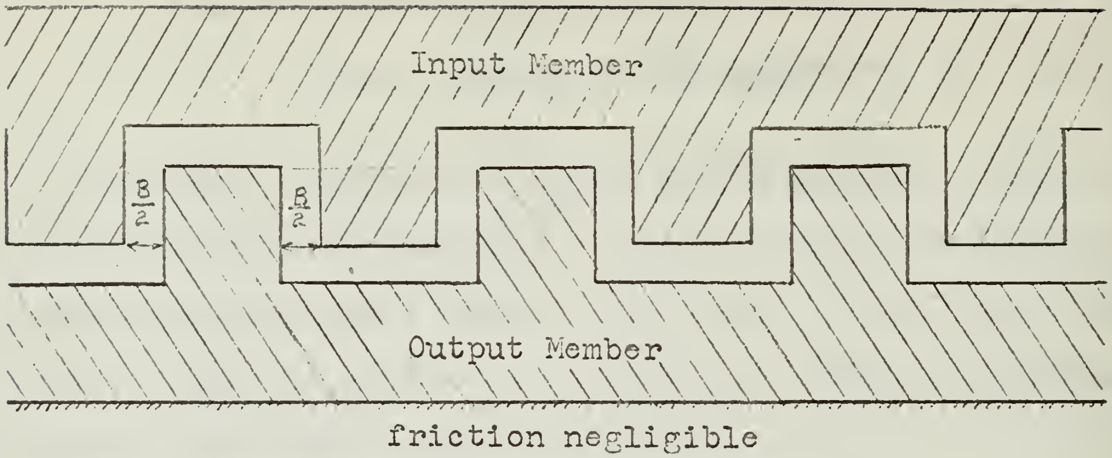
$$\theta_1 = \frac{1}{R} - \frac{\pi}{2} + \cos\theta_1$$

$$GD = \sqrt{x^2 + y^2} \quad \angle \tan^{-1}\frac{Y}{X}$$

Brearley showed that the system will become unstable for $R < .2685$. For this value, $\theta_1 = 122.49°$. Thus for

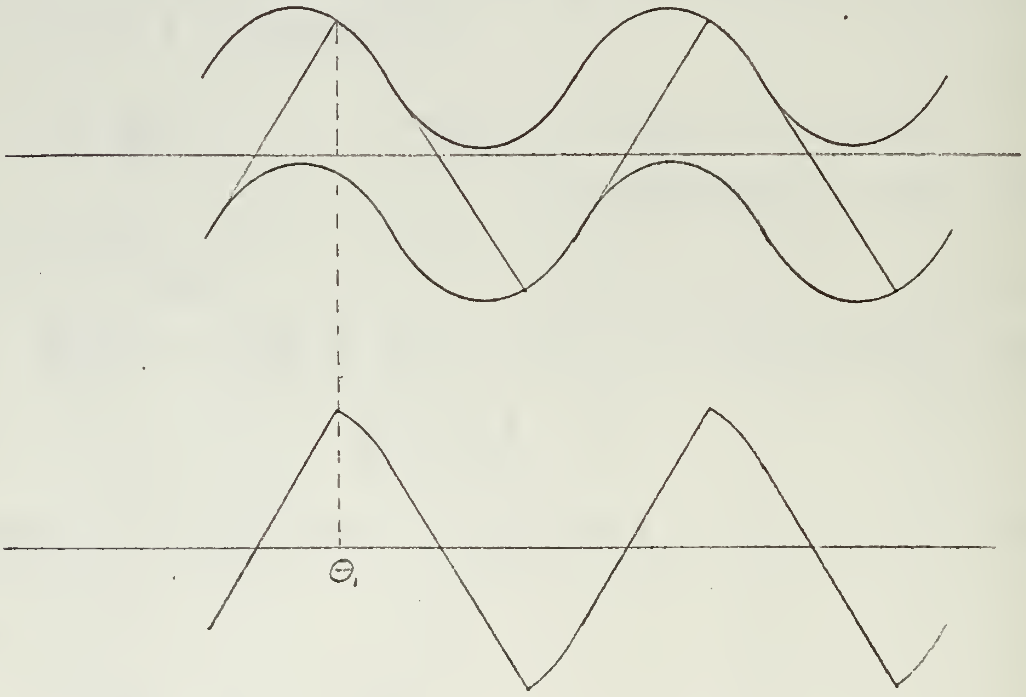
$\frac{1}{\pi} < R < .2685$ (corresponding to θ_1 between 90° and 122.49°) the describing function is:

$$GD = \frac{4}{\pi} \sin \theta_1 \quad -\theta_1$$



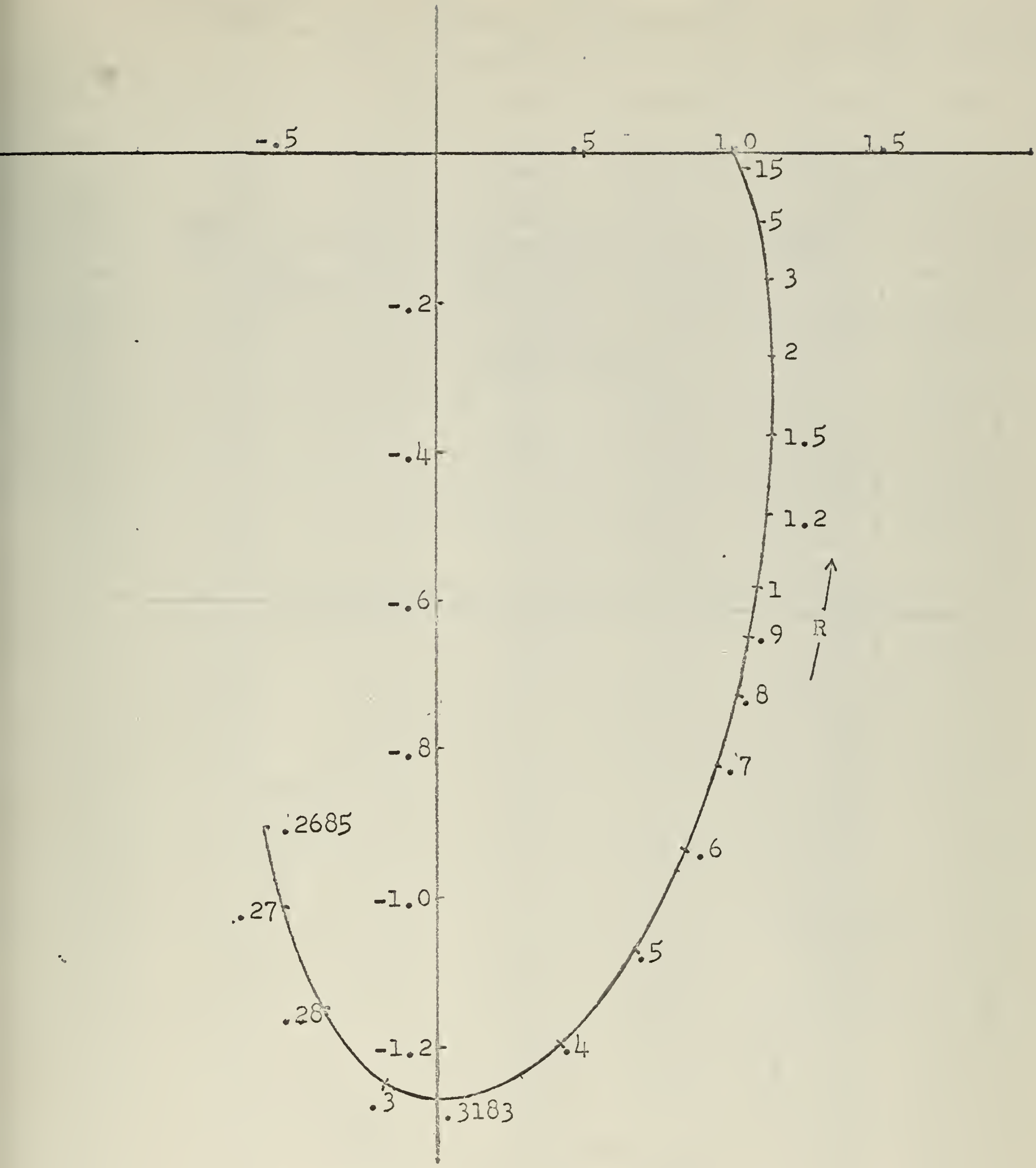
Physical model for inertia controlled backlash

Figure XII-1



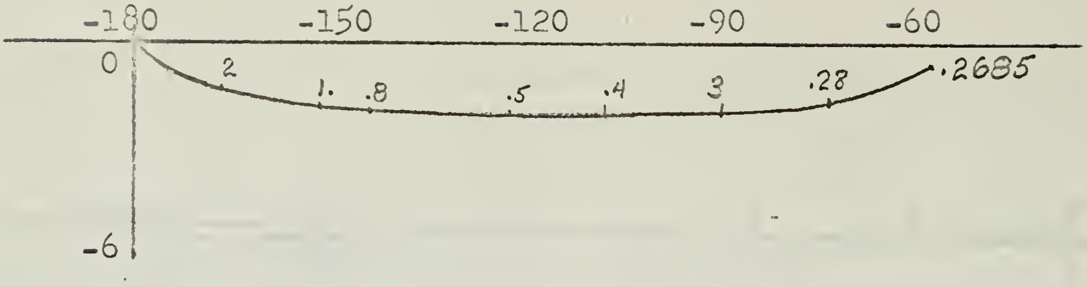
Input and output displacements for inertia controlled backlash

Figure XII-2



INERTIA CONTROLLED BACKLASH
REAL AND IMAGINARY COMPONENTS

Figure XII-3



INERTIA CONTROLLED BACKLASH
MAGNITUDE(DB) VS PHASE

Figure XII-4

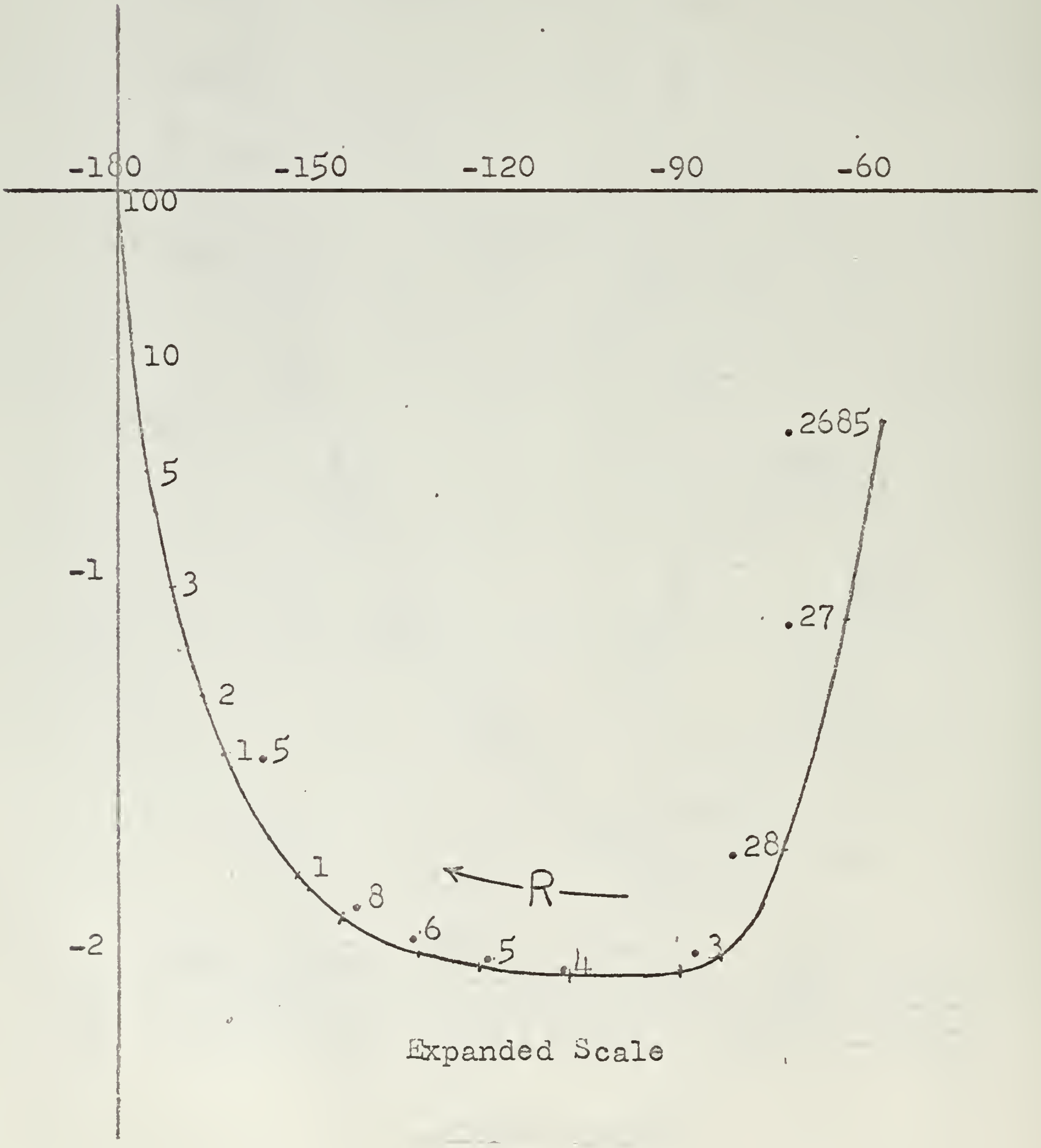


Figure XII-5

INERTIA CONTROLLED BACKLASH

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  PHI      REAL       IMAG       GD        PHASE   1/GD(DB)     THETA

 .2685    -.5769     -.9059    1.0740    -122.49     -.6197    -57.51
 .2685    -.5705     -.9191    1.0818    -121.83     -.6829    -58.17
 .2686    -.5638     -.9323    1.0895    -121.16     -.7445    -58.84
 .2687    -.5568     -.9452    1.0970    -120.50     -.8045    -59.50
 .2688    -.5495     -.9580    1.1045    -119.84     -.8629    -60.16
 .2690    -.5419     -.9707    1.1117    -119.17     -.9198    -60.83
 .2692    -.5341     -.9831    1.1188    -118.51     -.9752    -61.49
 .2694    -.5259     -.9954    1.1258    -117.85    -1.0290    -62.15
 .2697    -.5175    -1.0075    1.1326    -117.19    -1.0814    -62.81
 .2700    -.5087    -1.0193    1.1392    -116.52    -1.1323    -63.48
 .2703    -.4997    -1.0310    1.1457    -115.86    -1.1817    -64.14
 .2707    -.4905    -1.0425    1.1521    -115.20    -1.2297    -64.80
 .2711    -.4810    -1.0537    1.1583    -114.53    -1.2763    -65.47
 .2716    -.4712    -1.0647    1.1643    -113.87    -1.3215    -66.13
 .2721    -.4611    -1.0755    1.1702    -113.21    -1.3653    -66.79
 .2726    -.4509    -1.0861    1.1759    -112.54    -1.4077    -67.46
 .2732    -.4403    -1.0964    1.1815    -111.88    -1.4487    -68.12
 .2738    -.4296    -1.1065    1.1869    -111.22    -1.4884    -68.78
 .2744    -.4186    -1.1163    1.1922    -110.55    -1.5268    -69.45
 .2751    -.4074    -1.1258    1.1973    -109.89    -1.5638    -70.11
 .2759    -.3959    -1.1351    1.2022    -109.23    -1.5996    -70.77
 .2766    -.3843    -1.1442    1.2070    -108.57    -1.6340    -71.43
 .2774    -.3724    -1.1529    1.2116    -107.90    -1.6671    -72.10
 .2783    -.3604    -1.1614    1.2160    -107.24    -1.6989    -72.76
 .2792    -.3482    -1.1696    1.2203    -106.58    -1.7295    -73.42
 .2801    -.3357    -1.1775    1.2244    -105.91    -1.7588    -74.09
 .2811    -.3231    -1.1851    1.2284    -105.25    -1.7868    -74.75
 .2822    -.3103    -1.1925    1.2322    -104.59    -1.8136    -75.41
 .2832    -.2974    -1.1995    1.2358    -103.92    -1.8391    -76.08
 .2844    -.2843    -1.2062    1.2393    -103.26    -1.8634    -76.74
 .2855    -.2710    -1.2127    1.2426    -102.60    -1.8865    -77.40
 .2868    -.2576    -1.2188    1.2457    -101.94    -1.9083    -78.06
 .2880    -.2441    -1.2246    1.2487    -101.27    -1.9290    -78.73
 .2893    -.2304    -1.2301    1.2515    -100.61    -1.9484    -79.39
 .2907    -.2166    -1.2353    1.2541     -99.95    -1.9666    -80.05
 .2921    -.2027    -1.2401    1.2566     -99.28    -1.9837    -80.72
 .2936    -.1887    -1.2446    1.2589     -98.62    -1.9995    -81.38
 .2951    -.1746    -1.2488    1.2610     -97.96    -2.0142    -82.04
 .2967    -.1603    -1.2527    1.2629     -97.29    -2.0276    -82.71
 .2984    -.1460    -1.2563    1.2647     -96.63    -2.0399    -83.37
 .3001    -.1317    -1.2595    1.2663     -95.97    -2.0510    -84.03
 .3018    -.1172    -1.2624    1.2678     -95.30    -2.0609    -84.70
 .3037    -.1027    -1.2649    1.2691     -94.64    -2.0696    -85.36
 .3055    -.0881    -1.2671    1.2702     -93.98    -2.0772    -86.02
 .3075    -.0735    -1.2690    1.2711     -93.32    -2.0836    -86.68
 .3095    -.0589    -1.2705    1.2719     -92.65    -2.0889    -87.35
 .3116    -.0442    -1.2717    1.2725     -91.99    -2.0929    -88.01
 .3138    -.0295    -1.2726    1.2729     -91.33    -2.0959    -88.67
 .3160    -.0147    -1.2731    1.2732     -90.66    -2.0976    -89.34
 .3183    -.0000    -1.2732    1.2732     -90.00    -2.0982    -90.00
```

INERTIA CONTROLLED BACKLASH

PHI	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
.3200	.0106	-1.2732	1.2732	-89.52	-2.0982	-90.48
.3250	.0412	-1.2726	1.2732	-88.15	-2.0982	-91.85
.3300	.0708	-1.2713	1.2732	-86.81	-2.0982	-93.19
.3350	.0996	-1.2693	1.2732	-85.52	-2.0982	-94.48
.3400	.1274	-1.2668	1.2732	-84.26	-2.0982	-95.74
.3450	.1544	-1.2638	1.2732	-83.04	-2.0981	-96.96
.3500	.1805	-1.2604	1.2732	-81.85	-2.0981	-98.15
.3550	.2059	-1.2565	1.2732	-80.70	-2.0981	-99.30
.3600	.2303	-1.2522	1.2732	-79.58	-2.0980	-100.42
.3650	.2541	-1.2476	1.2732	-78.49	-2.0979	-101.51
.3700	.2772	-1.2426	1.2732	-77.43	-2.0978	-102.57
.3750	.2995	-1.2374	1.2732	-76.39	-2.0976	-103.61
.3800	.3212	-1.2320	1.2731	-75.39	-2.0974	-104.61
.3850	.3422	-1.2262	1.2731	-74.41	-2.0972	-105.59
.3900	.3625	-1.2203	1.2731	-73.46	-2.0969	-106.54
.3950	.3823	-1.2143	1.2730	-72.52	-2.0966	-107.48
.4000	.4014	-1.2080	1.2730	-71.62	-2.0962	-108.38
.4050	.4200	-1.2016	1.2729	-70.73	-2.0958	-109.27
.4100	.4380	-1.1951	1.2728	-69.87	-2.0954	-110.13
.4150	.4555	-1.1884	1.2728	-69.03	-2.0949	-110.97
.4200	.4725	-1.1817	1.2727	-68.21	-2.0943	-111.79
.4250	.4890	-1.1749	1.2726	-67.40	-2.0937	-112.60
.4300	.5050	-1.1680	1.2725	-66.62	-2.0931	-113.38
.4350	.5205	-1.1610	1.2724	-65.85	-2.0924	-114.15
.4400	.5356	-1.1541	1.2723	-65.10	-2.0916	-114.90
.4450	.5502	-1.1470	1.2722	-64.37	-2.0908	-115.63
.4500	.5645	-1.1399	1.2720	-63.66	-2.0899	-116.34
.4550	.5783	-1.1328	1.2719	-62.96	-2.0890	-117.04
.4600	.5917	-1.1257	1.2717	-62.27	-2.0880	-117.73
.4650	.6048	-1.1186	1.2716	-61.60	-2.0870	-118.40
.4700	.6175	-1.1114	1.2714	-60.94	-2.0859	-119.06
.4750	.6298	-1.1043	1.2713	-60.30	-2.0848	-119.70
.4800	.6418	-1.0972	1.2711	-59.67	-2.0836	-120.33
.4850	.6535	-1.0900	1.2709	-59.06	-2.0823	-120.94
.4900	.6649	-1.0829	1.2707	-58.45	-2.0810	-121.55
.4950	.6759	-1.0758	1.2705	-57.86	-2.0797	-122.14
.5000	.6866	-1.0688	1.2703	-57.28	-2.0783	-122.72
.5050	.6971	-1.0617	1.2701	-56.71	-2.0768	-123.29
.5100	.7073	-1.0547	1.2699	-56.15	-2.0753	-123.85
.5150	.7172	-1.0477	1.2697	-55.61	-2.0738	-124.39
.5200	.7268	-1.0408	1.2694	-55.07	-2.0722	-124.93
.5250	.7362	-1.0338	1.2692	-54.54	-2.0705	-125.46
.5300	.7454	-1.0270	1.2689	-54.03	-2.0689	-125.97
.5350	.7543	-1.0201	1.2687	-53.52	-2.0671	-126.48
.5400	.7630	-1.0133	1.2684	-53.02	-2.0654	-126.98
.5450	.7714	-1.0066	1.2682	-52.54	-2.0636	-127.46
.5500	.7796	-.9999	1.2679	-52.06	-2.0617	-127.94
.5550	.7876	-.9932	1.2676	-51.59	-2.0598	-128.41
.5600	.7954	-.9866	1.2673	-51.12	-2.0579	-128.88
.5650	.8031	-.9801	1.2671	-50.67	-2.0559	-129.33

```
                    INERTIA CONTROLLED BACKLASH

   PHI        REAL        IMAG        GD       PHASE   1/GD(DB)    THETA

  .5700      .8105      -.9735     1.2668    -50.22    -2.0539   -129.78
  .5750      .8177      -.9671     1.2665    -49.78    -2.0518   -130.22
  .5800      .8248      -.9606     1.2662    -49.35    -2.0498   -130.65
  .5850      .8317      -.9543     1.2658    -48.93    -2.0476   -131.07
  .5900      .8384      -.9480     1.2655    -48.51    -2.0455   -131.49
  .5950      .8450      -.9417     1.2652    -48.10    -2.0433   -131.90
  .6000      .8514      -.9355     1.2649    -47.69    -2.0411   -132.31
  .6050      .8576      -.9293     1.2646    -47.30    -2.0388   -132.70
  .6100      .8637      -.9232     1.2642    -46.91    -2.0366   -133.09
  .6150      .8696      -.9171     1.2639    -46.52    -2.0343   -133.48
  .6200      .8754      -.9111     1.2636    -46.14    -2.0319   -133.86
  .6250      .8811      -.9052     1.2632    -45.77    -2.0296   -134.23
  .6300      .8866      -.8993     1.2629    -45.41    -2.0272   -134.59
  .6350      .8920      -.8934     1.2625    -45.04    -2.0247   -134.96
  .6400      .8973      -.8876     1.2622    -44.69    -2.0223   -135.31
  .6450      .9025      -.8819     1.2618    -44.34    -2.0198   -135.66
  .6500      .9075      -.8762     1.2614    -43.99    -2.0173   -136.01
  .6550      .9124      -.8705     1.2611    -43.66    -2.0148   -136.34
  .6600      .9172      -.8650     1.2607    -43.32    -2.0123   -136.68
  .6650      .9219      -.8594     1.2603    -42.99    -2.0097   -137.01
  .6700      .9265      -.8539     1.2600    -42.67    -2.0072   -137.33
  .6750      .9309      -.8485     1.2596    -42.35    -2.0046   -137.65
  .6800      .9353      -.8431     1.2592    -42.03    -2.0020   -137.97
  .6850      .9395      -.8378     1.2588    -41.72    -1.9993   -138.28
  .6900      .9437      -.8325     1.2584    -41.42    -1.9967   -138.58
  .6950      .9478      -.8273     1.2581    -41.12    -1.9940   -138.88
  .7000      .9518      -.8221     1.2577    -40.82    -1.9913   -139.18
  .7050      .9557      -.8170     1.2573    -40.53    -1.9886   -139.47
  .7100      .9595      -.8119     1.2569    -40.24    -1.9859   -139.76
  .7150      .9632      -.8068     1.2565    -39.95    -1.9832   -140.05
  .7200      .9669      -.8018     1.2561    -39.67    -1.9804   -140.33
  .7250      .9704      -.7969     1.2557    -39.39    -1.9777   -140.61
  .7300      .9739      -.7920     1.2553    -39.12    -1.9749   -140.88
  .7350      .9773      -.7871     1.2549    -38.85    -1.9721   -141.15
  .7400      .9807      -.7823     1.2545    -38.58    -1.9693   -141.42
  .7450      .9839      -.7776     1.2541    -38.32    -1.9665   -141.68
  .7500      .9871      -.7728     1.2537    -38.06    -1.9637   -141.94
  .7550      .9903      -.7682     1.2533    -37.80    -1.9609   -142.20
  .7600      .9933      -.7635     1.2529    -37.55    -1.9580   -142.45
  .7650      .9963      -.7589     1.2524    -37.30    -1.9552   -142.70
  .7700      .9992      -.7544     1.2520    -37.05    -1.9523   -142.95
  .7750     1.0021      -.7499     1.2516    -36.81    -1.9495   -143.19
  .7800     1.0049      -.7454     1.2512    -36.57    -1.9466   -143.43
  .7850     1.0077      -.7410     1.2508    -36.33    -1.9437   -143.67
  .7900     1.0103      -.7367     1.2504    -36.10    -1.9408   -143.90
  .7950     1.0130      -.7323     1.2500    -35.86    -1.9379   -144.14
  .8000     1.0155      -.7280     1.2495    -35.64    -1.9350   -144.36
  .8500     1.0385      -.6873     1.2453    -33.50    -1.9058   -146.50
  .9000     1.0572      -.6501     1.2411    -31.59    -1.8762   -148.41
  .9500     1.0725      -.6162     1.2369    -29.88    -1.8467   -150.12
```

INERTIA CONTROLLED BACKLASH

PHI	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
1.0000	1.0850	-.5851	1.2327	-28.33	-1.8173	-151.67
1.0500	1.0953	-.5566	1.2286	-26.94	-1.7882	-153.06
1.1000	1.1038	-.5303	1.2246	-25.66	-1.7596	-154.34
1.1500	1.1107	-.5061	1.2206	-24.50	-1.7314	-155.50
1.2000	1.1164	-.4838	1.2167	-23.43	-1.7038	-156.57
1.2500	1.1211	-.4631	1.2129	-22.44	-1.6768	-157.56
1.3000	1.1249	-.4439	1.2093	-21.53	-1.6504	-158.47
1.3500	1.1279	-.4260	1.2057	-20.69	-1.6246	-159.31
1.4000	1.1304	-.4093	1.2022	-19.91	-1.5995	-160.09
1.4500	1.1323	-.3938	1.1988	-19.17	-1.5750	-160.83
1.5000	1.1338	-.3792	1.1955	-18.49	-1.5511	-161.51
1.5500	1.1349	-.3656	1.1923	-17.85	-1.5279	-162.15
1.6000	1.1357	-.3528	1.1892	-17.26	-1.5053	-162.74
1.6500	1.1362	-.3407	1.1862	-16.69	-1.4833	-163.31
1.7000	1.1365	-.3294	1.1833	-16.16	-1.4618	-163.84
1.7500	1.1366	-.3187	1.1804	-15.66	-1.4409	-164.34
1.8000	1.1365	-.3086	1.1777	-15.19	-1.4208	-164.81
1.8500	1.1363	-.2991	1.1750	-14.75	-1.4010	-165.25
1.9000	1.1360	-.2900	1.1724	-14.32	-1.3817	-165.68
1.9500	1.1355	-.2815	1.1699	-13.92	-1.3630	-166.08
2.0000	1.1350	-.2733	1.1674	-13.54	-1.3446	-166.46
2.0500	1.1344	-.2656	1.1650	-13.18	-1.3269	-166.82
2.1000	1.1337	-.2582	1.1627	-12.83	-1.3095	-167.17
2.1500	1.1329	-.2512	1.1605	-12.50	-1.2926	-167.50
2.2000	1.1321	-.2445	1.1583	-12.19	-1.2761	-167.81
2.2500	1.1313	-.2381	1.1561	-11.89	-1.2600	-168.11
2.3000	1.1305	-.2321	1.1540	-11.60	-1.2443	-168.40
2.3500	1.1296	-.2263	1.1520	-11.33	-1.2290	-168.67
2.4000	1.1286	-.2207	1.1500	-11.06	-1.2140	-168.94
2.4500	1.1277	-.2153	1.1481	-10.81	-1.1995	-169.19
2.5000	1.1268	-.2102	1.1462	-10.57	-1.1853	-169.43
2.5500	1.1258	-.2053	1.1444	-10.34	-1.1714	-169.66
2.6000	1.1248	-.2006	1.1426	-10.11	-1.1578	-169.89
2.6500	1.1239	-.1961	1.1408	-9.90	-1.1445	-170.10
2.7000	1.1229	-.1918	1.1391	-9.69	-1.1316	-170.31
2.7500	1.1219	-.1876	1.1375	-9.49	-1.1189	-170.51
2.8000	1.1209	-.1836	1.1359	-9.30	-1.1065	-170.70
2.8500	1.1200	-.1797	1.1343	-9.12	-1.0944	-170.88
2.9000	1.1190	-.1760	1.1327	-8.94	-1.0826	-171.06
2.9500	1.1180	-.1724	1.1312	-8.77	-1.0711	-171.23
3.0000	1.1171	-.1689	1.1298	-8.60	-1.0597	-171.40
3.0500	1.1161	-.1656	1.1283	-8.44	-1.0486	-171.56
3.1000	1.1151	-.1624	1.1269	-8.28	-1.0377	-171.72
3.1500	1.1142	-.1592	1.1255	-8.13	-1.0271	-171.87
3.2000	1.1133	-.1562	1.1242	-7.99	-1.0167	-172.01
3.2500	1.1123	-.1533	1.1229	-7.85	-1.0065	-172.15
3.3000	1.1114	-.1505	1.1216	-7.71	-.9965	-172.29
3.3500	1.1105	-.1478	1.1203	-7.58	-.9867	-172.42
3.4000	1.1096	-.1451	1.1191	-7.45	-.9771	-172.55
3.4500	1.1087	-.1425	1.1178	-7.33	-.9677	-172.67

INERTIA CONTROLLED BACKLASH

PHI	REAL	IMAG	GD	PHASE	1/GD(DB)	THETA
3.5000	1.1078	-.1401	1.1167	-7.21	-.9584	-172.79
3.5500	1.1070	-.1377	1.1155	-7.09	-.9494	-172.91
3.6000	1.1061	-.1353	1.1144	-6.97	-.9406	-173.03
3.6500	1.1053	-.1331	1.1133	-6.86	-.9319	-173.14
3.7000	1.1044	-.1308	1.1121	-6.76	-.9233	-173.24
3.7500	1.1036	-.1287	1.1111	-6.65	-.9149	-173.35
3.8000	1.1028	-.1266	1.1100	-6.55	-.9067	-173.45
3.8500	1.1020	-.1246	1.1090	-6.45	-.8986	-173.55
3.9000	1.1012	-.1226	1.1080	-6.36	-.8907	-173.64
3.9500	1.1004	-.1207	1.1070	-6.26	-.8828	-173.74
4.0000	1.0996	-.1189	1.1060	-6.17	-.8752	-173.83
4.0500	1.0988	-.1171	1.1051	-6.08	-.8677	-173.92
4.1000	1.0981	-.1153	1.1041	-5.99	-.8603	-174.01
4.1500	1.0973	-.1136	1.1032	-5.91	-.8531	-174.09
4.2000	1.0966	-.1119	1.1023	-5.83	-.8459	-174.17
4.2500	1.0959	-.1103	1.1014	-5.75	-.8389	-174.25
4.3000	1.0951	-.1087	1.1005	-5.67	-.8320	-174.33
4.3500	1.0944	-.1072	1.0997	-5.59	-.8252	-174.41
4.4000	1.0937	-.1057	1.0988	-5.52	-.8185	-174.48
4.4500	1.0930	-.1042	1.0980	-5.45	-.8120	-174.55
4.5000	1.0923	-.1027	1.0972	-5.37	-.8055	-174.63
4.5500	1.0917	-.1013	1.0964	-5.30	-.7991	-174.70
4.6000	1.0910	-.1000	1.0956	-5.24	-.7929	-174.76
4.6500	1.0904	-.0986	1.0948	-5.17	-.7868	-174.83
4.7000	1.0897	-.0973	1.0940	-5.10	-.7807	-174.90
4.7500	1.0891	-.0961	1.0933	-5.04	-.7747	-174.96
4.8000	1.0884	-.0948	1.0926	-4.98	-.7689	-175.02
4.8500	1.0878	-.0936	1.0918	-4.92	-.7631	-175.08
4.9000	1.0872	-.0924	1.0911	-4.86	-.7574	-175.14
4.9500	1.0866	-.0913	1.0904	-4.80	-.7518	-175.20
5.0000	1.0860	-.0901	1.0897	-4.74	-.7463	-175.26
5.5000	1.0804	-.0800	1.0834	-4.23	-.6954	-175.77
6.0000	1.0755	-.0717	1.0778	-3.81	-.6511	-176.19
6.5000	1.0711	-.0648	1.0730	-3.46	-.6123	-176.54
7.0000	1.0672	-.0590	1.0688	-3.17	-.5779	-176.83
7.5000	1.0637	-.0541	1.0650	-2.91	-.5472	-177.09
8.0000	1.0605	-.0498	1.0617	-2.69	-.5197	-177.31
8.5000	1.0576	-.0461	1.0586	-2.50	-.4949	-177.50
9.0000	1.0550	-.0429	1.0559	-2.33	-.4724	-177.67
9.5000	1.0526	-.0400	1.0534	-2.18	-.4519	-177.82
10.0000	1.0505	-.0375	1.0511	-2.04	-.4331	-177.96
10.5000	1.0485	-.0352	1.0490	-1.92	-.4159	-178.08
11.0000	1.0466	-.0331	1.0471	-1.81	-.4000	-178.19
11.5000	1.0449	-.0313	1.0454	-1.72	-.3853	-178.28
12.0000	1.0433	-.0296	1.0437	-1.63	-.3717	-178.37
12.5000	1.0418	-.0281	1.0422	-1.55	-.3589	-178.45
13.0000	1.0404	-.0267	1.0408	-1.47	-.3471	-178.53
13.5000	1.0391	-.0255	1.0394	-1.40	-.3360	-178.60
14.0000	1.0379	-.0243	1.0382	-1.34	-.3256	-178.66
14.5000	1.0368	-.0232	1.0370	-1.28	-.3159	-178.72

```
                         INERTIA CONTROLLED BACKLASH

     PHI         REAL        IMAG          GD        PHASE  1/GD(DB)      THETA

   15.0000     1.0357      -.0222      1.0359       -1.23     -.3068     -178.77
   15.5000     1.0347      -.0213      1.0349       -1.18     -.2981     -178.82
   16.0000     1.0337      -.0204      1.0339       -1.13     -.2900     -178.87
   16.5000     1.0328      -.0196      1.0330       -1.09     -.2822     -178.91
   17.0000     1.0320      -.0189      1.0322       -1.05     -.2749     -178.95
   17.5000     1.0312      -.0182      1.0313       -1.01     -.2680     -178.99
   18.0000     1.0304      -.0175      1.0305        -.98     -.2614     -179.02
   18.5000     1.0297      -.0169      1.0298        -.94     -.2551     -179.06
   19.0000     1.0290      -.0164      1.0291        -.91     -.2491     -179.09
   19.5000     1.0283      -.0158      1.0284        -.88     -.2435     -179.12
   20.0000     1.0277      -.0153      1.0278        -.85     -.2380     -179.15
   20.5000     1.0271      -.0148      1.0272        -.83     -.2328     -179.17
   21.0000     1.0265      -.0144      1.0266        -.80     -.2278     -179.20
   21.5000     1.0259      -.0139      1.0260        -.78     -.2231     -179.22
   22.0000     1.0254      -.0135      1.0255        -.76     -.2185     -179.24
   22.5000     1.0249      -.0131      1.0250        -.73     -.2142     -179.27
   23.0000     1.0244      -.0128      1.0245        -.71     -.2100     -179.29
   23.5000     1.0239      -.0124      1.0240        -.69     -.2059     -179.31
   24.0000     1.0235      -.0121      1.0235        -.68     -.2021     -179.32
   24.5000     1.0230      -.0118      1.0231        -.66     -.1983     -179.34
   25.0000     1.0226      -.0114      1.0227        -.64     -.1947     -179.36
   30.0000     1.0191      -.0090      1.0192        -.51     -.1648     -179.49
   35.0000     1.0166      -.0074      1.0166        -.42     -.1430     -179.58
   40.0000     1.0146      -.0062      1.0147        -.35     -.1263     -179.65
   45.0000     1.0131      -.0053      1.0131        -.30     -.1132     -179.70
   50.0000     1.0119      -.0046      1.0119        -.26     -.1025     -179.74
   60.0000     1.0100      -.0036      1.0100        -.21     -.0864     -179.79
   70.0000     1.0086      -.0030      1.0086        -.17     -.0746     -179.83
   80.0000     1.0076      -.0025      1.0076        -.14     -.0657     -179.86
   90.0000     1.0068      -.0021      1.0068        -.12     -.0587     -179.88
  100.0000     1.0061      -.0019      1.0061        -.11     -.0531     -179.89
  110.0000     1.0056      -.0016      1.0056        -.09     -.0485     -179.91
  120.0000     1.0051      -.0015      1.0051        -.08     -.0446     -179.92
  130.0000     1.0048      -.0013      1.0048        -.08     -.0413     -179.92
  140.0000     1.0044      -.0012      1.0044        -.07     -.0385     -179.93
  150.0000     1.0042      -.0011      1.0042        -.06     -.0360     -179.94
  160.0000     1.0039      -.0010      1.0039        -.06     -.0339     -179.94
  170.0000     1.0037      -.0009      1.0037        -.05     -.0319     -179.95
  180.0000     1.0035      -.0009      1.0035        -.05     -.0302     -179.95
  190.0000     1.0033      -.0008      1.0033        -.05     -.0287     -179.95
  200.0000     1.0032      -.0008      1.0032        -.04     -.0273     -179.96
  210.0000     1.0030      -.0007      1.0030        -.04     -.0261     -179.96
  220.0000     1.0029      -.0007      1.0029        -.04     -.0249     -179.96
  230.0000     1.0028      -.0006      1.0028        -.04     -.0239     -179.96
  240.0000     1.0026      -.0006      1.0026        -.03     -.0229     -179.97
  250.0000     1.0025      -.0006      1.0025        -.03     -.0221     -179.97
  260.0000     1.0024      -.0005      1.0024        -.03     -.0212     -179.97
  270.0000     1.0024      -.0005      1.0024        -.03     -.0205     -179.97
  280.0000     1.0023      -.0005      1.0023        -.03     -.0198     -179.97
  290.0000     1.0022      -.0005      1.0022        -.03     -.0191     -179.97
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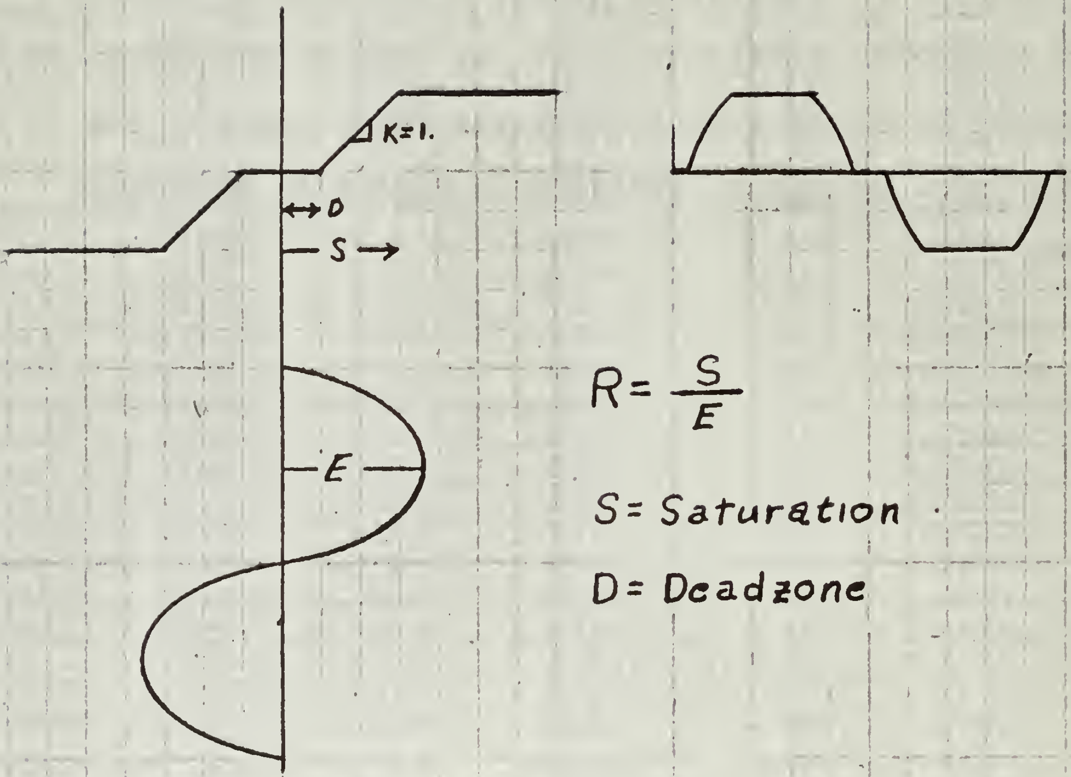
APPENDIX XIII

Deadzone and Saturation

Deadzone and saturation occurs frequently in systems having electronic amplifiers. It may also be the result of combining two separate nonlinearities which occur in the same path and are not separated by a frequency dependent element.



$$R = \frac{S}{E}$$

S = Saturation

D = Deadzone

$$G_D(j\omega) \doteq \frac{1}{\pi}\left[2\left(\sin^{-1}R - \sin^{-1}\frac{D}{E}\right) + \sin 2R - \sin\frac{2D}{E}\right]$$

$$\angle 0^\circ$$

Figure XIII
Deadzone and Saturation

DEAD ZONE AND SATURATION
D/S = .0

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	1.0000	-.0000	.9000	.9626	.3309
.9980	.9999	.0009	.8980	.9615	.3410
.9960	.9997	.0026	.8960	.9604	.3512
.9940	.9994	.0048	.8940	.9592	.3615
.9920	.9991	.0074	.8920	.9581	.3719
.9900	.9988	.0104	.8900	.9569	.3823
.9880	.9984	.0137	.8880	.9558	.3929
.9860	.9980	.0172	.8860	.9546	.4036
.9840	.9976	.0211	.8840	.9534	.4144
.9820	.9971	.0251	.8820	.9522	.4253
.9800	.9966	.0294	.8800	.9510	.4363
.9780	.9961	.0340	.8780	.9498	.4474
.9760	.9956	.0387	.8760	.9486	.4586
.9740	.9950	.0436	.8740	.9473	.4699
.9720	.9944	.0488	.8720	.9461	.4813
.9700	.9938	.0541	.8700	.9448	.4928
.9680	.9932	.0596	.8680	.9436	.5044
.9660	.9925	.0653	.8660	.9423	.5161
.9640	.9918	.0711	.8640	.9410	.5279
.9620	.9912	.0771	.8620	.9398	.5397
.9600	.9905	.0833	.8600	.9385	.5517
.9580	.9897	.0896	.8580	.9372	.5638
.9560	.9890	.0961	.8560	.9358	.5760
.9540	.9882	.1028	.8540	.9345	.5882
.9520	.9875	.1095	.8520	.9332	.6006
.9500	.9867	.1165	.8500	.9319	.6130
.9480	.9859	.1235	.8480	.9305	.6256
.9460	.9851	.1307	.8460	.9292	.6382
.9440	.9842	.1381	.8440	.9278	.6510
.9420	.9834	.1456	.8420	.9264	.6638
.9400	.9825	.1532	.8400	.9250	.6767
.9380	.9816	.1609	.8380	.9237	.6898
.9360	.9808	.1688	.8360	.9223	.7029
.9340	.9798	.1768	.8340	.9209	.7161
.9320	.9789	.1849	.8320	.9195	.7294
.9300	.9780	.1932	.8300	.9180	.7428
.9280	.9771	.2016	.8280	.9166	.7563
.9260	.9761	.2101	.8260	.9152	.7698
.9240	.9751	.2187	.8240	.9137	.7835
.9220	.9742	.2274	.8220	.9123	.7973
.9200	.9732	.2363	.8200	.9108	.8111
.9180	.9722	.2452	.8180	.9094	.8251
.9160	.9711	.2543	.8160	.9079	.8391
.9140	.9701	.2635	.8140	.9064	.8532
.9120	.9691	.2728	.8120	.9050	.8674
.9100	.9680	.2822	.8100	.9035	.8818
.9080	.9670	.2917	.8080	.9020	.8962
.9060	.9659	.3014	.8060	.9005	.9107
.9040	.9648	.3111	.8040	.8990	.9252
.9020	.9637	.3210	.8020	.8974	.9399

DEAD ZONE AND SATURATION

D/S = .0

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.8959	.9547	.7000	.8119	1.8102
.7980	.8944	.9695	.6980	.8101	1.8297
.7960	.8928	.9845	.6960	.8082	1.8493
.7940	.8913	.9995	.6940	.8064	1.8690
.7920	.8897	1.0147	.6920	.8046	1.8888
.7900	.8882	1.0299	.6900	.8027	1.9087
.7880	.8866	1.0452	.6880	.8009	1.9286
.7860	.8851	1.0606	.6860	.7990	1.9487
.7840	.8835	1.0761	.6840	.7972	1.9689
.7820	.8819	1.0917	.6820	.7953	1.9892
.7800	.8803	1.1074	.6800	.7934	2.0096
.7780	.8787	1.1231	.6780	.7916	2.0301
.7760	.8771	1.1390	.6760	.7897	2.0507
.7740	.8755	1.1549	.6740	.7878	2.0714
.7720	.8739	1.1710	.6720	.7859	2.0922
.7700	.8723	1.1871	.6700	.7841	2.1131
.7680	.8706	1.2033	.6680	.7822	2.1341
.7660	.8690	1.2197	.6660	.7803	2.1551
.7640	.8674	1.2361	.6640	.7784	2.1763
.7620	.8657	1.2526	.6620	.7765	2.1976
.7600	.8641	1.2692	.6600	.7745	2.2190
.7580	.8624	1.2858	.6580	.7726	2.2406
.7560	.8607	1.3026	.6560	.7707	2.2622
.7540	.8591	1.3195	.6540	.7688	2.2839
.7520	.8574	1.3364	.6520	.7669	2.3057
.7500	.8557	1.3535	.6500	.7649	2.3276
.7480	.8540	1.3706	.6480	.7630	2.3496
.7460	.8523	1.3879	.6460	.7610	2.3718
.7440	.8506	1.4052	.6440	.7591	2.3940
.7420	.8489	1.4226	.6420	.7572	2.4164
.7400	.8472	1.4401	.6400	.7552	2.4388
.7380	.8455	1.4577	.6380	.7532	2.4614
.7360	.8438	1.4754	.6360	.7513	2.4840
.7340	.8421	1.4932	.6340	.7493	2.5068
.7320	.8403	1.5111	.6320	.7473	2.5297
.7300	.8386	1.5291	.6300	.7454	2.5527
.7280	.8368	1.5472	.6280	.7434	2.5758
.7260	.8351	1.5653	.6260	.7414	2.5990
.7240	.8333	1.5836	.6240	.7394	2.6223
.7220	.8316	1.6020	.6220	.7374	2.6457
.7200	.8298	1.6204	.6200	.7354	2.6693
.7180	.8280	1.6390	.6180	.7334	2.6929
.7160	.8263	1.6576	.6160	.7314	2.7167
.7140	.8245	1.6763	.6140	.7294	2.7406
.7120	.8227	1.6952	.6120	.7274	2.7646
.7100	.8209	1.7141	.6100	.7254	2.7887
.7080	.8191	1.7331	.6080	.7234	2.8129
.7060	.8173	1.7522	.6060	.7213	2.8372
.7040	.8155	1.7714	.6040	.7193	2.8617
.7020	.8137	1.7908	.6020	.7173	2.8862

DEAD ZONE AND SATURATION
D/S = .0

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.7152	2.9109	.5000	.6090	4.3077
.5980	.7132	2.9357	.4980	.6068	4.3392
.5960	.7112	2.9606	.4960	.6046	4.3709
.5940	.7091	2.9857	.4940	.6024	4.4027
.5920	.7071	3.0108	.4920	.6002	4.4348
.5900	.7050	3.0361	.4900	.5979	4.4669
.5880	.7030	3.0615	.4880	.5957	4.4992
.5860	.7009	3.0870	.4860	.5935	4.5317
.5840	.6988	3.1126	.4840	.5913	4.5644
.5820	.6968	3.1384	.4820	.5890	4.5972
.5800	.6947	3.1643	.4800	.5868	4.6302
.5780	.6926	3.1903	.4780	.5846	4.6633
.5760	.6905	3.2164	.4760	.5823	4.6967
.5740	.6884	3.2426	.4740	.5801	4.7301
.5720	.6864	3.2690	.4720	.5778	4.7638
.5700	.6843	3.2955	.4700	.5756	4.7976
.5680	.6822	3.3221	.4680	.5733	4.8316
.5660	.6801	3.3489	.4660	.5711	4.8658
.5640	.6780	3.3757	.4640	.5688	4.9002
.5620	.6759	3.4027	.4620	.5666	4.9347
.5600	.6738	3.4299	.4600	.5643	4.9694
.5580	.6717	3.4571	.4580	.5621	5.0043
.5560	.6695	3.4845	.4560	.5598	5.0394
.5540	.6674	3.5121	.4540	.5575	5.0746
.5520	.6653	3.5397	.4520	.5553	5.1101
.5500	.6632	3.5675	.4500	.5530	5.1457
.5480	.6610	3.5954	.4480	.5507	5.1815
.5460	.6589	3.6235	.4460	.5484	5.2175
.5440	.6568	3.6517	.4440	.5462	5.2537
.5420	.6546	3.6800	.4420	.5439	5.2901
.5400	.6525	3.7085	.4400	.5416	5.3267
.5380	.6504	3.7371	.4380	.5393	5.3635
.5360	.6482	3.7658	.4360	.5370	5.4004
.5340	.6461	3.7947	.4340	.5347	5.4376
.5320	.6439	3.8237	.4320	.5324	5.4750
.5300	.6417	3.8528	.4300	.5301	5.5125
.5280	.6396	3.8821	.4280	.5278	5.5503
.5260	.6374	3.9116	.4260	.5255	5.5883
.5240	.6352	3.9412	.4240	.5232	5.6265
.5220	.6331	3.9709	.4220	.5209	5.6648
.5200	.6309	4.0008	.4200	.5186	5.7034
.5180	.6287	4.0308	.4180	.5163	5.7423
.5160	.6265	4.0609	.4160	.5140	5.7813
.5140	.6244	4.0913	.4140	.5117	5.8205
.5120	.6222	4.1217	.4120	.5093	5.8600
.5100	.6200	4.1523	.4100	.5070	5.8997
.5080	.6178	4.1831	.4080	.5047	5.9396
.5060	.6156	4.2140	.4060	.5024	5.9797
.5040	.6134	4.2451	.4040	.5000	6.0200
.5020	.6112	4.2763	.4020	.4977	6.0606

DEAD ZONE AND SATURATION

D/S = .0

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.4954	6.1014	.3000	.3762	8.4925
.3980	.4930	6.1425	.2980	.3737	8.5488
.3960	.4907	6.1837	.2960	.3713	8.6055
.3940	.4884	6.2252	.2940	.3689	8.6626
.3920	.4860	6.2670	.2920	.3664	8.7201
.3900	.4837	6.3090	.2900	.3640	8.7780
.3880	.4813	6.3512	.2880	.3616	8.8364
.3860	.4790	6.3937	.2860	.3591	8.8952
.3840	.4766	6.4364	.2840	.3567	8.9545
.3820	.4743	6.4794	.2820	.3542	9.0141
.3800	.4719	6.5226	.2800	.3518	9.0743
.3780	.4696	6.5661	.2780	.3493	9.1349
.3760	.4672	6.6098	.2760	.3469	9.1959
.3740	.4648	6.6538	.2740	.3445	9.2574
.3720	.4625	6.6981	.2720	.3420	9.3194
.3700	.4601	6.7426	.2700	.3396	9.3819
.3680	.4578	6.7874	.2680	.3371	9.4449
.3660	.4554	6.8325	.2660	.3346	9.5083
.3640	.4530	6.8778	.2640	.3322	9.5723
.3620	.4506	6.9234	.2620	.3297	9.6368
.3600	.4483	6.9693	.2600	.3273	9.7018
.3580	.4459	7.0155	.2580	.3248	9.7673
.3560	.4435	7.0620	.2560	.3224	9.8334
.3540	.4411	7.1087	.2540	.3199	9.9000
.3520	.4387	7.1557	.2520	.3174	9.9671
.3500	.4364	7.2031	.2500	.3150	10.0348
.3480	.4340	7.2507	.2480	.3125	10.1031
.3460	.4316	7.2986	.2460	.3100	10.1720
.3440	.4292	7.3469	.2440	.3076	10.2414
.3420	.4268	7.3954	.2420	.3051	10.3114
.3400	.4244	7.4443	.2400	.3026	10.3821
.3380	.4220	7.4935	.2380	.3001	10.4534
.3360	.4196	7.5429	.2360	.2977	10.5252
.3340	.4172	7.5927	.2340	.2952	10.5978
.3320	.4148	7.6429	.2320	.2927	10.6709
.3300	.4124	7.6933	.2300	.2902	10.7448
.3280	.4100	7.7441	.2280	.2878	10.8193
.3260	.4076	7.7953	.2260	.2853	10.8945
.3240	.4052	7.8467	.2240	.2828	10.9703
.3220	.4028	7.8986	.2220	.2803	11.0469
.3200	.4004	7.9507	.2200	.2778	11.1242
.3180	.3980	8.0032	.2180	.2754	11.2022
.3160	.3955	8.0561	.2160	.2729	11.2810
.3140	.3931	8.1093	.2140	.2704	11.3605
.3120	.3907	8.1629	.2120	.2679	11.4408
.3100	.3883	8.2169	.2100	.2654	11.5219
.3080	.3859	8.2713	.2080	.2629	11.6038
.3060	.3834	8.3260	.2060	.2604	11.6865
.3040	.3810	8.3811	.2040	.2579	11.7700
.3020	.3786	8.4366	.2020	.2554	11.8544

DEAD ZONE AND SATURATION
D/S = .0

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.2000	.2529	11.9396	.1000	.1271	17.9163
.1980	.2504	12.0258	.0980	.1246	18.0912
.1960	.2479	12.1128	.0960	.1220	18.2697
.1940	.2455	12.2007	.0940	.1195	18.4521
.1920	.2430	12.2896	.0920	.1170	18.6383
.1900	.2405	12.3794	.0900	.1144	18.8287
.1880	.2380	12.4702	.0880	.1119	19.0234
.1860	.2355	12.5620	.0860	.1094	19.2225
.1840	.2329	12.6548	.0840	.1068	19.4264
.1820	.2304	12.7487	.0820	.1043	19.6353
.1800	.2279	12.8436	.0800	.1018	19.8493
.1780	.2254	12.9396	.0780	.0992	20.0687
.1760	.2229	13.0367	.0760	.0967	20.2939
.1740	.2204	13.1349	.0740	.0941	20.5251
.1720	.2179	13.2343	.0720	.0916	20.7627
.1700	.2154	13.3349	.0700	.0891	21.0069
.1680	.2129	13.4367	.0680	.0865	21.2583
.1660	.2104	13.5398	.0660	.0840	21.5172
.1640	.2079	13.6441	.0640	.0814	21.7841
.1620	.2054	13.7497	.0620	.0789	22.0595
.1600	.2028	13.8567	.0600	.0763	22.3440
.1580	.2003	13.9650	.0580	.0738	22.6381
.1560	.1978	14.0747	.0560	.0713	22.9426
.1540	.1953	14.1859	.0540	.0687	23.2581
.1520	.1928	14.2985	.0520	.0662	23.5856
.1500	.1903	14.4127	.0500	.0636	23.9260
.1480	.1877	14.5284	.0480	.0611	24.2803
.1460	.1852	14.6457	.0460	.0585	24.6497
.1440	.1827	14.7647	.0440	.0560	25.0355
.1420	.1802	14.8854	.0420	.0535	25.4394
.1400	.1777	15.0077	.0400	.0509	25.8629
.1380	.1751	15.1319	.0380	.0484	26.3082
.1360	.1726	15.2579	.0360	.0458	26.7776
.1340	.1701	15.3858	.0340	.0433	27.2739
.1320	.1676	15.5156	.0320	.0407	27.8003
.1300	.1651	15.6475	.0300	.0382	28.3607
.1280	.1625	15.7814	.0280	.0356	28.9598
.1260	.1600	15.9174	.0260	.0331	29.6033
.1240	.1575	16.0557	.0240	.0306	30.2984
.1220	.1549	16.1962	.0220	.0280	31.0540
.1200	.1524	16.3391	.0200	.0255	31.8818
.1180	.1499	16.4844	.0180	.0229	32.7968
.1160	.1474	16.6322	.0160	.0204	33.8198
.1140	.1448	16.7826	.0140	.0178	34.9795
.1120	.1423	16.9356	.0120	.0153	36.3184
.1100	.1398	17.0915	.0100	.0127	37.9019
.1080	.1372	17.2502	.0080	.0102	39.8401
.1060	.1347	17.4120	.0060	.0076	42.3388
.1040	.1322	17.5768	.0040	.0051	45.8606
.1020	.1296	17.7449	.0020	.0025	51.8812

DEAD ZONE AND SATURATION
D/S = .2

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	.7471	2.5329	.9000	.7347	2.6781
.9980	.7475	2.5283	.8980	.7341	2.6854
.9960	.7478	2.5248	.8960	.7334	2.6928
.9940	.7480	2.5220	.8940	.7328	2.7003
.9920	.7482	2.5197	.8920	.7322	2.7079
.9900	.7484	2.5178	.8900	.7315	2.7157
.9880	.7485	2.5164	.8880	.7308	2.7236
.9860	.7486	2.5153	.8860	.7302	2.7316
.9840	.7486	2.5147	.8840	.7295	2.7398
.9820	.7487	2.5143	.8820	.7288	2.7480
.9800	.7487	2.5142	.8800	.7281	2.7564
.9780	.7486	2.5144	.8780	.7274	2.7649
.9760	.7486	2.5150	.8760	.7266	2.7736
.9740	.7485	2.5157	.8740	.7259	2.7823
.9720	.7485	2.5167	.8720	.7252	2.7912
.9700	.7483	2.5180	.8700	.7244	2.8001
.9680	.7482	2.5195	.8680	.7237	2.8092
.9660	.7481	2.5212	.8660	.7229	2.8185
.9640	.7479	2.5232	.8640	.7221	2.8278
.9620	.7477	2.5254	.8620	.7213	2.8372
.9600	.7475	2.5277	.8600	.7205	2.8468
.9580	.7473	2.5303	.8580	.7197	2.8565
.9560	.7470	2.5331	.8560	.7189	2.8663
.9540	.7468	2.5361	.8540	.7181	2.8762
.9520	.7465	2.5392	.8520	.7173	2.8862
.9500	.7462	2.5426	.8500	.7164	2.8963
.9480	.7459	2.5461	.8480	.7156	2.9065
.9460	.7456	2.5498	.8460	.7148	2.9169
.9440	.7453	2.5537	.8440	.7139	2.9273
.9420	.7449	2.5577	.8420	.7130	2.9379
.9400	.7446	2.5619	.8400	.7122	2.9486
.9380	.7442	2.5663	.8380	.7113	2.9593
.9360	.7438	2.5709	.8360	.7104	2.9702
.9340	.7434	2.5756	.8340	.7095	2.9812
.9320	.7430	2.5804	.8320	.7086	2.9923
.9300	.7426	2.5854	.8300	.7077	3.0036
.9280	.7421	2.5906	.8280	.7067	3.0149
.9260	.7417	2.5959	.8260	.7058	3.0263
.9240	.7412	2.6014	.8240	.7049	3.0378
.9220	.7407	2.6070	.8220	.7039	3.0495
.9200	.7402	2.6128	.8200	.7030	3.0612
.9180	.7397	2.6187	.8180	.7020	3.0731
.9160	.7392	2.6248	.8160	.7010	3.0850
.9140	.7387	2.6309	.8140	.7001	3.0971
.9120	.7381	2.6373	.8120	.6991	3.1093
.9100	.7376	2.6437	.8100	.6981	3.1216
.9080	.7370	2.6503	.8080	.6971	3.1339
.9060	.7365	2.6571	.8060	.6961	3.1464
.9040	.7359	2.6640	.8040	.6951	3.1590
.9020	.7353	2.6710	.8020	.6941	3.1717

DEAD ZONE AND SATURATION
D/S = .2

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.6931	3.1845	-.7000	.6342	3.9553
.7980	.6920	3.1974	.6980	.6329	3.9734
.7960	.6910	3.2104	.6960	.6316	3.9915
.7940	.6900	3.2235	.6940	.6302	4.0098
.7920	.6889	3.2367	.6920	.6289	4.0282
.7900	.6879	3.2500	.6900	.6276	4.0466
.7880	.6868	3.2634	.6880	.6262	4.0652
.7860	.6857	3.2770	.6860	.6249	4.0839
.7840	.6847	3.2906	.6840	.6235	4.1027
.7820	.6836	3.3043	.6820	.6222	4.1216
.7800	.6825	3.3181	.6800	.6208	4.1406
.7780	.6814	3.3321	.6780	.6195	4.1597
.7760	.6803	3.3461	.6760	.6181	4.1790
.7740	.6792	3.3602	.6740	.6167	4.1983
.7720	.6781	3.3745	.6720	.6153	4.2177
.7700	.6770	3.3888	.6700	.6140	4.2373
.7680	.6758	3.4033	.6680	.6126	4.2570
.7660	.6747	3.4178	.6660	.6112	4.2767
.7640	.6736	3.4324	.6640	.6098	4.2966
.7620	.6724	3.4472	.6620	.6084	4.3166
.7600	.6713	3.4620	.6600	.6070	4.3367
.7580	.6701	3.4770	.6580	.6056	4.3569
.7560	.6690	3.4920	.6560	.6041	4.3772
.7540	.6678	3.5072	.6540	.6027	4.3976
.7520	.6666	3.5225	.6520	.6013	4.4182
.7500	.6654	3.5378	.6500	.5999	4.4388
.7480	.6643	3.5533	.6480	.5984	4.4596
.7460	.6631	3.5689	.6460	.5970	4.4805
.7440	.6619	3.5845	.6440	.5956	4.5015
.7420	.6607	3.6003	.6420	.5941	4.5226
.7400	.6595	3.6162	.6400	.5927	4.5438
.7380	.6583	3.6321	.6380	.5912	4.5651
.7360	.6570	3.6482	.6360	.5898	4.5866
.7340	.6558	3.6644	.6340	.5883	4.6081
.7320	.6546	3.6807	.6320	.5868	4.6298
.7300	.6534	3.6971	.6300	.5854	4.6516
.7280	.6521	3.7136	.6280	.5839	4.6735
.7260	.6509	3.7302	.6260	.5824	4.6955
.7240	.6496	3.7469	.6240	.5809	4.7176
.7220	.6484	3.7637	.6220	.5794	4.7399
.7200	.6471	3.7806	.6200	.5779	4.7623
.7180	.6458	3.7976	.6180	.5765	4.7848
.7160	.6446	3.8147	.6160	.5750	4.8074
.7140	.6433	3.8319	.6140	.5734	4.8301
.7120	.6420	3.8492	.6120	.5719	4.8530
.7100	.6407	3.8666	.6100	.5704	4.8759
.7080	.6394	3.8842	.6080	.5689	4.8990
.7060	.6381	3.9018	.6060	.5674	4.9222
.7040	.6368	3.9195	.6040	.5659	4.9455
.7020	.6355	3.9374	.6020	.5644	4.9690

DEAD ZONE AND SATURATION

D/S = .2

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.5628	4.9926	.5000-	.4819	6.3411
.5980	.5613	5.0163	.4980	.4802	6.3718
.5960	.5598	5.0401	.4960	.4785	6.4027
.5940	.5582	5.0640	.4940	.4768	6.4337
.5920	.5567	5.0881	.4920	.4751	6.4649
.5900	.5551	5.1123	.4900	.4734	6.4962
.5880	.5536	5.1366	.4880	.4716	6.5277
.5860	.5520	5.1611	.4860	.4699	6.5594
.5840	.5504	5.1856	.4840	.4682	6.5913
.5820	.5489	5.2103	.4820	.4665	6.6233
.5800	.5473	5.2352	.4800	.4648	6.6555
.5780	.5457	5.2601	.4780	.4630	6.6878
.5760	.5442	5.2852	.4760	.4613	6.7204
.5740	.5426	5.3104	.4740	.4596	6.7531
.5720	.5410	5.3358	.4720	.4578	6.7860
.5700	.5394	5.3613	.4700	.4561	6.8190
.5680	.5378	5.3869	.4680	.4543	6.8523
.5660	.5363	5.4126	.4660	.4526	6.8857
.5640	.5347	5.4385	.4640	.4509	6.9193
.5620	.5331	5.4645	.4620	.4491	6.9531
.5600	.5315	5.4906	.4600	.4474	6.9870
.5580	.5299	5.5169	.4580	.4456	7.0212
.5560	.5282	5.5433	.4560	.4438	7.0555
.5540	.5266	5.5699	.4540	.4421	7.0900
.5520	.5250	5.5966	.4520	.4403	7.1247
.5500	.5234	5.6234	.4500	.4385	7.1596
.5480	.5218	5.6503	.4480	.4368	7.1947
.5460	.5201	5.6774	.4460	.4350	7.2300
.5440	.5185	5.7047	.4440	.4332	7.2655
.5420	.5169	5.7321	.4420	.4315	7.3012
.5400	.5153	5.7596	.4400	.4297	7.3370
.5380	.5136	5.7873	.4380	.4279	7.3731
.5360	.5120	5.8151	.4360	.4261	7.4094
.5340	.5103	5.8430	.4340	.4243	7.4458
.5320	.5087	5.8711	.4320	.4225	7.4825
.5300	.5070	5.8994	.4300	.4208	7.5194
.5280	.5054	5.9278	.4280	.4190	7.5565
.5260	.5037	5.9563	.4260	.4172	7.5938
.5240	.5021	5.9850	.4240	.4154	7.6313
.5220	.5004	6.0138	.4220	.4136	7.6690
.5200	.4987	6.0428	.4200	.4118	7.7069
.5180	.4971	6.0719	.4180	.4100	7.7451
.5160	.4954	6.1012	.4160	.4082	7.7835
.5140	.4937	6.1307	.4140	.4063	7.8221
.5120	.4920	6.1603	.4120	.4045	7.8609
.5100	.4903	6.1900	.4100	.4027	7.8999
.5080	.4887	6.2199	.4080	.4009	7.9392
.5060	.4870	6.2500	.4060	.3991	7.9786
.5040	.4853	6.2802	.4040	.3973	8.0184
.5020	.4836	6.3106	.4020	.3954	8.0583

DEAD ZONE AND SATURATION
D/S = .2

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.3936	8.0985	.3000	.2998	10.4630
.3980	.3918	8.1389	.2980	.2979	10.5188
.3960	.3900	8.1796	.2960	.2960	10.5751
.3940	.3881	8.2205	.2940	.2940	10.6317
.3920	.3863	8.2616	.2920	.2921	10.6888
.3900	.3845	8.3030	.2900	.2902	10.7463
.3880	.3826	8.3446	.2880	.2883	10.8043
.3860	.3808	8.3865	.2860	.2863	10.8627
.3840	.3789	8.4286	.2840	.2844	10.9215
.3820	.3771	8.4710	.2820	.2825	10.9807
.3800	.3752	8.5136	.2800	.2805	11.0405
.3780	.3734	8.5565	.2780	.2786	11.1006
.3760	.3715	8.5997	.2760	.2767	11.1613
.3740	.3697	8.6431	.2740	.2747	11.2224
.3720	.3678	8.6868	.2720	.2728	11.2840
.3700	.3660	8.7308	.2700	.2708	11.3461
.3680	.3641	8.7750	.2680	.2689	11.4086
.3660	.3623	8.8195	.2660	.2669	11.4717
.3640	.3604	8.8643	.2640	.2650	11.5353
.3620	.3585	8.9093	.2620	.2630	11.5994
.3600	.3567	8.9547	.2600	.2611	11.6640
.3580	.3548	9.0003	.2580	.2591	11.7292
.3560	.3529	9.0462	.2560	.2572	11.7948
.3540	.3511	9.0924	.2540	.2552	11.8611
.3520	.3492	9.1389	.2520	.2533	11.9279
.3500	.3473	9.1857	.2500	.2513	11.9952
.3480	.3454	9.2328	.2480	.2494	12.0631
.3460	.3435	9.2802	.2460	.2474	12.1316
.3440	.3417	9.3280	.2440	.2455	12.2007
.3420	.3398	9.3760	.2420	.2435	12.2704
.3400	.3379	9.4243	.2400	.2415	12.3407
.3380	.3360	9.4730	.2380	.2396	12.4116
.3360	.3341	9.5220	.2360	.2376	12.4832
.3340	.3322	9.5713	.2340	.2356	12.5554
.3320	.3303	9.6209	.2320	.2337	12.6282
.3300	.3284	9.6709	.2300	.2317	12.7017
.3280	.3265	9.7212	.2280	.2297	12.7759
.3260	.3246	9.7718	.2260	.2278	12.8507
.3240	.3227	9.8228	.2240	.2258	12.9263
.3220	.3208	9.8741	.2220	.2238	13.0025
.3200	.3189	9.9258	.2200	.2218	13.0795
.3180	.3170	9.9778	.2180	.2199	13.1572
.3160	.3151	10.0302	.2160	.2179	13.2357
.3140	.3132	10.0830	.2140	.2159	13.3149
.3120	.3113	10.1361	.2120	.2139	13.3949
.3100	.3094	10.1896	.2100	.2119	13.4757
.3080	.3075	10.2435	.2080	.2100	13.5573
.3060	.3056	10.2978	.2060	.2080	13.6397
.3040	.3037	10.3525	.2040	.2060	13.7229
.3020	.3017	10.4075	.2020	.2040	13.8070

DEAD ZONE AND SATURATION

D/S = .2

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.2000	.2020	13.8919	.1000	.1016	19.8580
.1980	.2000	13.9778	.0980	.0996	20.0328
.1960	.1980	14.0645	.0960	.0976	20.2111
.1940	.1961	14.1522	.0940	.0956	20.3933
.1920	.1941	14.2408	.0920	.0935	20.5795
.1900	.1921	14.3303	.0900	.0915	20.7697
.1880	.1901	14.4209	.0880	.0895	20.9643
.1860	.1881	14.5124	.0860	.0875	21.1633
.1840	.1861	14.6049	.0840	.0854	21.3671
.1820	.1841	14.6985	.0820	.0834	21.5758
.1800	.1821	14.7932	.0800	.0814	21.7897
.1780	.1801	14.8889	.0780	.0794	22.0090
.1760	.1781	14.9858	.0760	.0773	22.2341
.1740	.1761	15.0838	.0740	.0753	22.4652
.1720	.1741	15.1829	.0720	.0733	22.7027
.1700	.1721	15.2833	.0700	.0712	22.9468
.1680	.1701	15.3848	.0680	.0692	23.1981
.1660	.1681	15.4876	.0660	.0672	23.4569
.1640	.1661	15.5917	.0640	.0651	23.7238
.1620	.1641	15.6971	.0620	.0631	23.9991
.1600	.1621	15.8038	.0600	.0611	24.2834
.1580	.1601	15.9119	.0580	.0590	24.5775
.1560	.1581	16.0215	.0560	.0570	24.8819
.1540	.1561	16.1324	.0540	.0550	25.1974
.1520	.1541	16.2448	.0520	.0529	25.5248
.1500	.1521	16.3588	.0500	.0509	25.8651
.1480	.1501	16.4743	.0480	.0489	26.2193
.1460	.1481	16.5914	.0460	.0468	26.5886
.1440	.1460	16.7102	.0440	.0448	26.9744
.1420	.1440	16.8306	.0420	.0428	27.3782
.1400	.1420	16.9528	.0400	.0407	27.8017
.1380	.1400	17.0768	.0380	.0387	28.2469
.1360	.1380	17.2026	.0360	.0367	28.7163
.1340	.1360	17.3303	.0340	.0346	29.2125
.1320	.1340	17.4599	.0320	.0326	29.7388
.1300	.1320	17.5916	.0300	.0306	30.2992
.1280	.1299	17.7253	.0280	.0285	30.8982
.1260	.1279	17.8612	.0260	.0265	31.5417
.1240	.1259	17.9993	.0240	.0244	32.2368
.1220	.1239	18.1396	.0220	.0224	32.9924
.1200	.1219	18.2823	.0200	.0204	33.8201
.1180	.1198	18.4274	.0180	.0183	34.7351
.1160	.1178	18.5751	.0160	.0163	35.7580
.1140	.1158	18.7253	.0140	.0143	36.9178
.1120	.1138	18.8782	.0120	.0122	38.2566
.1100	.1118	19.0339	.0100	.0102	39.8402
.1080	.1097	19.1925	.0080	.0081	41.7783
.1060	.1077	19.3541	.0060	.0061	44.2770
.1040	.1057	19.5188	.0040	.0041	47.7988
.1020	.1037	19.6867	.0020	.0020	53.8194

DEAD ZONE AND SATURATION
D/S = .4

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	.5046	5.9405	.9000	.5144	5.7748
.9980	.5055	5.9263	.8980	.5142	5.7776
.9960	.5062	5.9136	.8960	.5140	5.7805
.9940	.5069	5.9020	.8940	.5138	5.7837
.9920	.5075	5.8911	.8920	.5136	5.7870
.9900	.5081	5.8809	.8900	.5134	5.7904
.9880	.5087	5.8714	.8880	.5132	5.7940
.9860	.5092	5.8624	.8860	.5130	5.7978
.9840	.5097	5.8539	.8840	.5128	5.8018
.9820	.5102	5.8459	.8820	.5125	5.8059
.9800	.5106	5.8384	.8800	.5123	5.8101
.9780	.5110	5.8313	.8780	.5120	5.8146
.9760	.5114	5.8246	.8760	.5117	5.8191
.9740	.5118	5.8182	.8740	.5115	5.8239
.9720	.5121	5.8123	.8720	.5112	5.8288
.9700	.5125	5.8067	.8700	.5109	5.8338
.9680	.5128	5.8015	.8680	.5106	5.8390
.9660	.5131	5.7965	.8660	.5103	5.8443
.9640	.5133	5.7919	.8640	.5099	5.8498
.9620	.5136	5.7876	.8620	.5096	5.8554
.9600	.5138	5.7837	.8600	.5093	5.8612
.9580	.5140	5.7800	.8580	.5089	5.8671
.9560	.5142	5.7765	.8560	.5086	5.8732
.9540	.5144	5.7734	.8540	.5082	5.8794
.9520	.5146	5.7705	.8520	.5078	5.8858
.9500	.5148	5.7679	.8500	.5074	5.8923
.9480	.5149	5.7656	.8480	.5071	5.8989
.9460	.5150	5.7635	.8460	.5067	5.9057
.9440	.5151	5.7616	.8440	.5063	5.9126
.9420	.5152	5.7600	.8420	.5058	5.9196
.9400	.5153	5.7586	.8400	.5054	5.9268
.9380	.5154	5.7574	.8380	.5050	5.9341
.9360	.5154	5.7565	.8360	.5046	5.9416
.9340	.5155	5.7558	.8340	.5041	5.9492
.9320	.5155	5.7553	.8320	.5037	5.9569
.9300	.5155	5.7551	.8300	.5032	5.9648
.9280	.5155	5.7550	.8280	.5028	5.9728
.9260	.5155	5.7552	.8260	.5023	5.9809
.9240	.5155	5.7555	.8240	.5018	5.9892
.9220	.5155	5.7561	.8220	.5013	5.9976
.9200	.5154	5.7568	.8200	.5008	6.0061
.9180	.5154	5.7578	.8180	.5003	6.0148
.9160	.5153	5.7590	.8160	.4998	6.0235
.9140	.5152	5.7603	.8140	.4993	6.0325
.9120	.5151	5.7618	.8120	.4988	6.0415
.9100	.5150	5.7635	.8100	.4983	6.0507
.9080	.5149	5.7654	.8080	.4977	6.0600
.9060	.5148	5.7675	.8060	.4972	6.0694
.9040	.5146	5.7698	.8040	.4967	6.0789
.9020	.5145	5.7722	.8020	.4961	6.0886

DEAD ZONE AND SATURATION
D/S = .4

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.4955	6.0984	.7000	.4601	6.7432
.7980	.4950	6.1084	.6980	.4592	6.7591
.7960	.4944	6.1184	.6960	.4584	6.7752
.7940	.4938	6.1286	.6940	.4575	6.7913
.7920	.4932	6.1389	.6920	.4567	6.8076
.7900	.4926	6.1493	.6900	.4558	6.8240
.7880	.4920	6.1599	.6880	.4550	6.8406
.7860	.4914	6.1705	.6860	.4541	6.8572
.7840	.4908	6.1813	.6840	.4532	6.8740
.7820	.4902	6.1922	.6820	.4523	6.8909
.7800	.4896	6.2033	.6800	.4514	6.9079
.7780	.4890	6.2145	.6780	.4506	6.9250
.7760	.4883	6.2257	.6760	.4497	6.9422
.7740	.4877	6.2371	.6740	.4488	6.9596
.7720	.4870	6.2487	.6720	.4479	6.9771
.7700	.4864	6.2603	.6700	.4470	6.9947
.7680	.4857	6.2721	.6680	.4460	7.0124
.7660	.4851	6.2840	.6660	.4451	7.0303
.7640	.4844	6.2960	.6640	.4442	7.0482
.7620	.4837	6.3081	.6620	.4433	7.0663
.7600	.4830	6.3204	.6600	.4424	7.0845
.7580	.4824	6.3327	.6580	.4414	7.1029
.7560	.4817	6.3452	.6560	.4405	7.1213
.7540	.4810	6.3578	.6540	.4395	7.1399
.7520	.4803	6.3706	.6520	.4386	7.1586
.7500	.4795	6.3834	.6500	.4377	7.1774
.7480	.4788	6.3964	.6480	.4367	7.1964
.7460	.4781	6.4095	.6460	.4357	7.2154
.7440	.4774	6.4227	.6440	.4348	7.2346
.7420	.4767	6.4360	.6420	.4338	7.2540
.7400	.4759	6.4495	.6400	.4328	7.2734
.7380	.4752	6.4630	.6380	.4319	7.2930
.7360	.4744	6.4767	.6360	.4309	7.3127
.7340	.4737	6.4905	.6340	.4299	7.3325
.7320	.4729	6.5044	.6320	.4289	7.3524
.7300	.4721	6.5184	.6300	.4279	7.3725
.7280	.4714	6.5326	.6280	.4269	7.3927
.7260	.4706	6.5469	.6260	.4259	7.4130
.7240	.4698	6.5613	.6240	.4249	7.4335
.7220	.4690	6.5758	.6220	.4239	7.4540
.7200	.4683	6.5904	.6200	.4229	7.4747
.7180	.4675	6.6051	.6180	.4219	7.4956
.7160	.4667	6.6200	.6160	.4209	7.5165
.7140	.4659	6.6350	.6140	.4199	7.5376
.7120	.4650	6.6501	.6120	.4188	7.5588
.7100	.4642	6.6653	.6100	.4178	7.5802
.7080	.4634	6.6807	.6080	.4168	7.6017
.7060	.4626	6.6961	.6060	.4158	7.6233
.7040	.4618	6.7117	.6040	.4147	7.6450
.7020	.4609	6.7274	.6020	.4137	7.6669

DEAD ZONE AND SATURATION
D/S = .4

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.4126	7.6889	.5000	.3561	8.9696
.5980	.4116	7.7110	.4980	.3548	8.9991
.5960	.4105	7.7333	.4960	.3536	9.0288
.5940	.4095	7.7557	.4940	.3524	9.0587
.5920	.4084	7.7782	.4920	.3512	9.0887
.5900	.4073	7.8009	.4900	.3500	9.1190
.5880	.4063	7.8237	.4880	.3488	9.1493
.5860	.4052	7.8466	.4860	.3475	9.1799
.5840	.4041	7.8697	.4840	.3463	9.2106
.5820	.4030	7.8929	.4820	.3451	9.2416
.5800	.4020	7.9163	.4800	.3438	9.2726
.5780	.4009	7.9397	.4780	.3426	9.3039
.5760	.3998	7.9634	.4760	.3414	9.3354
.5740	.3987	7.9871	.4740	.3401	9.3670
.5720	.3976	8.0110	.4720	.3389	9.3988
.5700	.3965	8.0351	.4700	.3376	9.4308
.5680	.3954	8.0592	.4680	.3364	9.4630
.5660	.3943	8.0836	.4660	.3351	9.4953
.5640	.3932	8.1080	.4640	.3339	9.5279
.5620	.3921	8.1326	.4620	.3326	9.5606
.5600	.3910	8.1574	.4600	.3314	9.5936
.5580	.3898	8.1823	.4580	.3301	9.6267
.5560	.3887	8.2073	.4560	.3289	9.6600
.5540	.3876	8.2325	.4540	.3276	9.6935
.5520	.3865	8.2578	.4520	.3263	9.7272
.5500	.3853	8.2833	.4500	.3250	9.7611
.5480	.3842	8.3089	.4480	.3238	9.7952
.5460	.3831	8.3346	.4460	.3225	9.8295
.5440	.3819	8.3605	.4440	.3212	9.8640
.5420	.3808	8.3866	.4420	.3199	9.8987
.5400	.3796	8.4128	.4400	.3187	9.9336
.5380	.3785	8.4392	.4380	.3174	9.9687
.5360	.3773	8.4657	.4360	.3161	10.0040
.5340	.3762	8.4923	.4340	.3148	10.0395
.5320	.3750	8.5192	.4320	.3135	10.0752
.5300	.3738	8.5461	.4300	.3122	10.1112
.5280	.3727	8.5732	.4280	.3109	10.1473
.5260	.3715	8.6005	.4260	.3096	10.1837
.5240	.3703	8.6279	.4240	.3083	10.2203
.5220	.3692	8.6555	.4220	.3070	10.2571
.5200	.3680	8.6833	.4200	.3057	10.2941
.5180	.3668	8.7112	.4180	.3044	10.3313
.5160	.3656	8.7392	.4160	.3031	10.3688
.5140	.3644	8.7675	.4140	.3018	10.4065
.5120	.3633	8.7959	.4120	.3005	10.4444
.5100	.3621	8.8244	.4100	.2991	10.4826
.5080	.3609	8.8531	.4080	.2978	10.5209
.5060	.3597	8.8820	.4060	.2965	10.5595
.5040	.3585	8.9110	.4040	.2952	10.5984
.5020	.3573	8.9402	.4020	.2939	10.6375

DEAD ZONE AND SATURATION
D/S = .4

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.2925	10.6768	.3000	.2237	13.0051
.3980	.2912	10.7164	.2980	.2223	13.0603
.3960	.2899	10.7562	.2960	.2209	13.1160
.3940	.2885	10.7962	.2940	.2195	13.1721
.3920	.2872	10.8365	.2920	.2181	13.2286
.3900	.2859	10.8771	.2900	.2166	13.2855
.3880	.2845	10.9179	.2880	.2152	13.3429
.3860	.2832	10.9589	.2860	.2138	13.4007
.3840	.2818	11.0003	.2840	.2124	13.4589
.3820	.2805	11.0418	.2820	.2109	13.5176
.3800	.2791	11.0837	.2800	.2095	13.5768
.3780	.2778	11.1258	.2780	.2081	13.6364
.3760	.2764	11.1681	.2760	.2066	13.6965
.3740	.2751	11.2108	.2740	.2052	13.7571
.3720	.2737	11.2537	.2720	.2037	13.8182
.3700	.2724	11.2969	.2700	.2023	13.8797
.3680	.2710	11.3403	.2680	.2009	13.9417
.3660	.2696	11.3841	.2660	.1994	14.0043
.3640	.2683	11.4281	.2640	.1980	14.0673
.3620	.2669	11.4724	.2620	.1965	14.1309
.3600	.2656	11.5170	.2600	.1951	14.1950
.3580	.2642	11.5619	.2580	.1936	14.2597
.3560	.2628	11.6070	.2560	.1922	14.3248
.3540	.2614	11.6525	.2540	.1908	14.3906
.3520	.2601	11.6983	.2520	.1893	14.4569
.3500	.2587	11.7444	.2500	.1879	14.5237
.3480	.2573	11.7907	.2480	.1864	14.5912
.3460	.2559	11.8374	.2460	.1849	14.6592
.3440	.2546	11.8844	.2440	.1835	14.7278
.3420	.2532	11.9318	.2420	.1820	14.7970
.3400	.2518	11.9794	.2400	.1806	14.8668
.3380	.2504	12.0274	.2380	.1791	14.9373
.3360	.2490	12.0757	.2360	.1777	15.0084
.3340	.2476	12.1243	.2340	.1762	15.0801
.3320	.2462	12.1732	.2320	.1747	15.1525
.3300	.2448	12.2225	.2300	.1733	15.2255
.3280	.2434	12.2722	.2280	.1718	15.2993
.3260	.2420	12.3221	.2260	.1703	15.3737
.3240	.2406	12.3725	.2240	.1689	15.4488
.3220	.2392	12.4231	.2220	.1674	15.5246
.3200	.2378	12.4742	.2200	.1659	15.6012
.3180	.2364	12.5256	.2180	.1645	15.6785
.3160	.2350	12.5773	.2160	.1630	15.7565
.3140	.2336	12.6294	.2140	.1615	15.8353
.3120	.2322	12.6819	.2120	.1600	15.9149
.3100	.2308	12.7348	.2100	.1586	15.9953
.3080	.2294	12.7881	.2080	.1571	16.0764
.3060	.2280	12.8417	.2060	.1556	16.1585
.3040	.2266	12.8958	.2040	.1541	16.2413
.3020	.2252	12.9502	.2020	.1527	16.3250

DEAD ZONE AND SATURATION

D/S = .4

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.2000	.1512	16.4096	.1000	.0762	22.3614
.1980	.1497	16.4950	.0980	.0747	22.5360
.1960	.1482	16.5814	.0960	.0732	22.7142
.1940	.1467	16.6687	.0940	.0716	22.8962
.1920	.1453	16.7569	.0920	.0701	23.0822
.1900	.1438	16.8461	.0900	.0686	23.2723
.1880	.1423	16.9363	.0880	.0671	23.4666
.1860	.1408	17.0274	.0860	.0656	23.6655
.1840	.1393	17.1196	.0840	.0641	23.8691
.1820	.1378	17.2129	.0820	.0625	24.0777
.1800	.1363	17.3072	.0800	.0610	24.2914
.1780	.1349	17.4026	.0780	.0595	24.5106
.1760	.1334	17.4991	.0760	.0580	24.7356
.1740	.1319	17.5968	.0740	.0565	24.9665
.1720	.1304	17.6956	.0720	.0549	25.2038
.1700	.1289	17.7956	.0700	.0534	25.4479
.1680	.1274	17.8968	.0680	.0519	25.6990
.1660	.1259	17.9993	.0660	.0504	25.9577
.1640	.1244	18.1031	.0640	.0488	26.2244
.1620	.1229	18.2082	.0620	.0473	26.4996
.1600	.1214	18.3146	.0600	.0458	26.7839
.1580	.1199	18.4224	.0580	.0443	27.0778
.1560	.1184	18.5316	.0560	.0427	27.3821
.1540	.1169	18.6423	.0540	.0412	27.6975
.1520	.1154	18.7544	.0520	.0397	28.0248
.1500	.1139	18.8681	.0500	.0382	28.3650
.1480	.1124	18.9833	.0480	.0366	28.7191
.1460	.1109	19.1001	.0460	.0351	29.0884
.1440	.1094	19.2186	.0440	.0336	29.4741
.1420	.1079	19.3388	.0420	.0321	29.8778
.1400	.1064	19.4607	.0400	.0305	30.3012
.1380	.1049	19.5844	.0380	.0290	30.7464
.1360	.1034	19.7100	.0360	.0275	31.2156
.1340	.1019	19.8374	.0340	.0260	31.7118
.1320	.1004	19.9668	.0320	.0244	32.2381
.1300	.0989	20.0983	.0300	.0229	32.7984
.1280	.0974	20.2317	.0280	.0214	33.3974
.1260	.0959	20.3674	.0260	.0199	34.0408
.1240	.0943	20.5052	.0240	.0183	34.7358
.1220	.0928	20.6453	.0220	.0168	35.4914
.1200	.0913	20.7878	.0200	.0153	36.3191
.1180	.0898	20.9327	.0180	.0137	37.2340
.1160	.0883	21.0801	.0160	.0122	38.2569
.1140	.0868	21.2301	.0140	.0107	39.4166
.1120	.0853	21.3828	.0120	.0092	40.7555
.1100	.0838	21.5383	.0100	.0076	42.3390
.1080	.0823	21.6967	.0080	.0061	44.2771
.1060	.0807	21.8581	.0060	.0046	46.7758
.1040	.0792	22.0226	.0040	.0031	50.2976
.1020	.0777	22.1903	.0020	.0015	56.3182

DEAD ZONE AND SATURATION

D/S = .6

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	.2848	10.9105	.9000	.3101	10.1694
.9980	.2859	10.8765	.8980	.3103	10.1646
.9960	.2869	10.8454	.8960	.3105	10.1601
.9940	.2879	10.8160	.8940	.3106	10.1558
.9920	.2888	10.7881	.8920	.3107	10.1518
.9900	.2897	10.7614	.8900	.3109	10.1480
.9880	.2905	10.7359	.8880	.3110	10.1445
.9860	.2914	10.7113	.8860	.3111	10.1412
.9840	.2922	10.6877	.8840	.3112	10.1381
.9820	.2929	10.6650	.8820	.3113	10.1353
.9800	.2937	10.6430	.8800	.3114	10.1328
.9780	.2944	10.6218	.8780	.3115	10.1304
.9760	.2951	10.6013	.8760	.3116	10.1283
.9740	.2957	10.5815	.8740	.3117	10.1264
.9720	.2964	10.5624	.8720	.3117	10.1248
.9700	.2970	10.5439	.8700	.3118	10.1233
.9680	.2976	10.5259	.8680	.3118	10.1221
.9660	.2982	10.5086	.8660	.3118	10.1211
.9640	.2988	10.4917	.8640	.3119	10.1203
.9620	.2994	10.4755	.8620	.3119	10.1198
.9600	.2999	10.4597	.8600	.3119	10.1194
.9580	.3005	10.4444	.8580	.3119	10.1192
.9560	.3010	10.4296	.8560	.3119	10.1193
.9540	.3015	10.4153	.8540	.3119	10.1195
.9520	.3019	10.4014	.8520	.3119	10.1200
.9500	.3024	10.3880	.8500	.3119	10.1207
.9480	.3029	10.3750	.8480	.3118	10.1215
.9460	.3033	10.3624	.8460	.3118	10.1226
.9440	.3037	10.3502	.8440	.3118	10.1238
.9420	.3041	10.3384	.8420	.3117	10.1253
.9400	.3045	10.3270	.8400	.3116	10.1269
.9380	.3049	10.3160	.8380	.3116	10.1287
.9360	.3053	10.3053	.8360	.3115	10.1307
.9340	.3057	10.2951	.8340	.3114	10.1329
.9320	.3060	10.2851	.8320	.3113	10.1353
.9300	.3064	10.2755	.8300	.3112	10.1379
.9280	.3067	10.2663	.8280	.3111	10.1406
.9260	.3070	10.2574	.8260	.3110	10.1436
.9240	.3073	10.2488	.8240	.3109	10.1467
.9220	.3076	10.2406	.8220	.3108	10.1500
.9200	.3079	10.2326	.8200	.3107	10.1534
.9180	.3081	10.2250	.8180	.3106	10.1571
.9160	.3084	10.2177	.8160	.3104	10.1609
.9140	.3087	10.2106	.8140	.3103	10.1649
.9120	.3089	10.2039	.8120	.3101	10.1691
.9100	.3091	10.1975	.8100	.3100	10.1734
.9080	.3093	10.1913	.8080	.3098	10.1779
.9060	.3095	10.1854	.8060	.3096	10.1826
.9040	.3097	10.1798	.8040	.3095	10.1875
.9020	.3099	10.1745	.8020	.3093	10.1925

DEAD ZONE AND SATURATION
D/S = .6

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.3091	10.1977	-.7000	.2933	10.6542
.7980	.3089	10.2030	.6980	.2929	10.6670
.7960	.3087	10.2086	.6960	.2924	10.6800
.7940	.3085	10.2142	.6940	.2920	10.6932
.7920	.3083	10.2201	.6920	.2915	10.7065
.7900	.3081	10.2261	.6900	.2911	10.7199
.7880	.3079	10.2322	.6880	.2906	10.7335
.7860	.3077	10.2386	.6860	.2902	10.7472
.7840	.3074	10.2451	.6840	.2897	10.7610
.7820	.3072	10.2517	.6820	.2892	10.7750
.7800	.3070	10.2585	.6800	.2888	10.7892
.7780	.3067	10.2655	.6780	.2883	10.8034
.7760	.3065	10.2726	.6760	.2878	10.8178
.7740	.3062	10.2799	.6740	.2873	10.8324
.7720	.3059	10.2873	.6720	.2868	10.8471
.7700	.3057	10.2949	.6700	.2864	10.8619
.7680	.3054	10.3026	.6680	.2859	10.8769
.7660	.3051	10.3105	.6660	.2854	10.8920
.7640	.3048	10.3186	.6640	.2849	10.9073
.7620	.3046	10.3268	.6620	.2844	10.9227
.7600	.3043	10.3351	.6600	.2839	10.9382
.7580	.3040	10.3436	.6580	.2833	10.9539
.7560	.3037	10.3523	.6560	.2828	10.9697
.7540	.3034	10.3611	.6540	.2823	10.9857
.7520	.3030	10.3701	.6520	.2818	11.0018
.7500	.3027	10.3792	.6500	.2813	11.0180
.7480	.3024	10.3884	.6480	.2807	11.0344
.7460	.3021	10.3978	.6460	.2802	11.0509
.7440	.3017	10.4074	.6440	.2797	11.0676
.7420	.3014	10.4171	.6420	.2791	11.0844
.7400	.3011	10.4269	.6400	.2786	11.1014
.7380	.3007	10.4369	.6380	.2780	11.1185
.7360	.3004	10.4470	.6360	.2775	11.1357
.7340	.3000	10.4573	.6340	.2769	11.1531
.7320	.2996	10.4677	.6320	.2764	11.1706
.7300	.2993	10.4783	.6300	.2758	11.1882
.7280	.2989	10.4890	.6280	.2752	11.2061
.7260	.2985	10.4999	.6260	.2747	11.2240
.7240	.2982	10.5109	.6240	.2741	11.2421
.7220	.2978	10.5221	.6220	.2735	11.2603
.7200	.2974	10.5334	.6200	.2729	11.2787
.7180	.2970	10.5448	.6180	.2724	11.2972
.7160	.2966	10.5564	.6160	.2718	11.3159
.7140	.2962	10.5681	.6140	.2712	11.3347
.7120	.2958	10.5800	.6120	.2706	11.3537
.7100	.2954	10.5920	.6100	.2700	11.3728
.7080	.2950	10.6041	.6080	.2694	11.3920
.7060	.2946	10.6164	.6060	.2688	11.4114
.7040	.2941	10.6289	.6040	.2682	11.4309
.7020	.2937	10.6415	.6020	.2676	11.4506

DEAD ZONE AND SATURATION
D/S = .6

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.2670	11.4704	.5000	.2328	12.6590
.5980	.2664	11.4904	.4980	.2321	12.6870
.5960	.2658	11.5105	.4960	.2313	12.7152
.5940	.2651	11.5308	.4940	.2306	12.7435
.5920	.2645	11.5512	.4920	.2298	12.7720
.5900	.2639	11.5718	.4900	.2291	12.8007
.5880	.2633	11.5925	.4880	.2283	12.8296
.5860	.2626	11.6134	.4860	.2275	12.8587
.5840	.2620	11.6344	.4840	.2268	12.8880
.5820	.2614	11.6555	.4820	.2260	12.9174
.5800	.2607	11.6769	.4800	.2252	12.9470
.5780	.2601	11.6983	.4780	.2245	12.9768
.5760	.2594	11.7199	.4760	.2237	13.0069
.5740	.2588	11.7417	.4740	.2229	13.0371
.5720	.2581	11.7636	.4720	.2221	13.0674
.5700	.2575	11.7857	.4700	.2214	13.0980
.5680	.2568	11.8079	.4680	.2206	13.1288
.5660	.2561	11.8303	.4660	.2198	13.1598
.5640	.2555	11.8528	.4640	.2190	13.1909
.5620	.2548	11.8755	.4620	.2182	13.2223
.5600	.2541	11.8984	.4600	.2174	13.2539
.5580	.2535	11.9214	.4580	.2166	13.2856
.5560	.2528	11.9445	.4560	.2158	13.3176
.5540	.2521	11.9678	.4540	.2150	13.3497
.5520	.2514	11.9913	.4520	.2142	13.3821
.5500	.2508	12.0149	.4500	.2134	13.4147
.5480	.2501	12.0387	.4480	.2126	13.4475
.5460	.2494	12.0627	.4460	.2118	13.4804
.5440	.2487	12.0868	.4440	.2110	13.5136
.5420	.2480	12.1111	.4420	.2102	13.5471
.5400	.2473	12.1355	.4400	.2094	13.5807
.5380	.2466	12.1601	.4380	.2086	13.6145
.5360	.2459	12.1848	.4360	.2078	13.6486
.5340	.2452	12.2097	.4340	.2069	13.6828
.5320	.2445	12.2348	.4320	.2061	13.7173
.5300	.2438	12.2601	.4300	.2053	13.7520
.5280	.2431	12.2855	.4280	.2045	13.7869
.5260	.2424	12.3111	.4260	.2037	13.8221
.5240	.2416	12.3368	.4240	.2028	13.8574
.5220	.2409	12.3627	.4220	.2020	13.8930
.5200	.2402	12.3888	.4200	.2012	13.9289
.5180	.2395	12.4150	.4180	.2003	13.9649
.5160	.2387	12.4414	.4160	.1995	14.0012
.5140	.2380	12.4680	.4140	.1987	14.0377
.5120	.2373	12.4948	.4120	.1978	14.0745
.5100	.2365	12.5217	.4100	.1970	14.1115
.5080	.2358	12.5488	.4080	.1961	14.1487
.5060	.2351	12.5761	.4060	.1953	14.1862
.5040	.2343	12.6036	.4040	.1944	14.2239
.5020	.2336	12.6312	.4020	.1936	14.2619

DEAD ZONE AND SATURATION

D/S = .6

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.1928	14.3001	.3000	.1482	16.5817
.3980	.1919	14.3385	.2980	.1473	16.6362
.3960	.1910	14.3773	.2960	.1464	16.6911
.3940	.1902	14.4162	.2940	.1454	16.7464
.3920	.1893	14.4554	.2920	.1445	16.8022
.3900	.1885	14.4949	.2900	.1436	16.8584
.3880	.1876	14.5346	.2880	.1426	16.9150
.3860	.1868	14.5746	.2860	.1417	16.9721
.3840	.1859	14.6149	.2840	.1408	17.0296
.3820	.1850	14.6554	.2820	.1398	17.0876
.3800	.1842	14.6962	.2800	.1389	17.1460
.3780	.1833	14.7373	.2780	.1380	17.2050
.3760	.1824	14.7786	.2760	.1370	17.2644
.3740	.1815	14.8202	.2740	.1361	17.3242
.3720	.1807	14.8621	.2720	.1351	17.3846
.3700	.1798	14.9043	.2700	.1342	17.4455
.3680	.1789	14.9468	.2680	.1332	17.5068
.3660	.1780	14.9895	.2660	.1323	17.5687
.3640	.1772	15.0326	.2640	.1314	17.6311
.3620	.1763	15.0759	.2620	.1304	17.6940
.3600	.1754	15.1195	.2600	.1295	17.7575
.3580	.1745	15.1634	.2580	.1285	17.8215
.3560	.1736	15.2077	.2560	.1276	17.8860
.3540	.1727	15.2522	.2540	.1266	17.9511
.3520	.1718	15.2970	.2520	.1256	18.0168
.3500	.1710	15.3422	.2500	.1247	18.0830
.3480	.1701	15.3876	.2480	.1237	18.1498
.3460	.1692	15.4334	.2460	.1228	18.2172
.3440	.1683	15.4795	.2440	.1218	18.2852
.3420	.1674	15.5259	.2420	.1209	18.3539
.3400	.1665	15.5726	.2400	.1199	18.4231
.3380	.1656	15.6197	.2380	.1189	18.4930
.3360	.1647	15.6671	.2360	.1180	18.5635
.3340	.1638	15.7149	.2340	.1170	18.6346
.3320	.1629	15.7629	.2320	.1161	18.7064
.3300	.1620	15.8114	.2300	.1151	18.7789
.3280	.1611	15.8601	.2280	.1141	18.8521
.3260	.1602	15.9093	.2260	.1132	18.9259
.3240	.1592	15.9587	.2240	.1122	19.0005
.3220	.1583	16.0086	.2220	.1112	19.0758
.3200	.1574	16.0588	.2200	.1103	19.1518
.3180	.1565	16.1093	.2180	.1093	19.2285
.3160	.1556	16.1603	.2160	.1083	19.3060
.3140	.1547	16.2116	.2140	.1073	19.3843
.3120	.1538	16.2633	.2120	.1064	19.4634
.3100	.1528	16.3154	.2100	.1054	19.5432
.3080	.1519	16.3678	.2080	.1044	19.6239
.3060	.1510	16.4207	.2060	.1034	19.7054
.3040	.1501	16.4739	.2040	.1025	19.7878
.3020	.1491	16.5276	.2020	.1015	19.8710

DEAD ZONE AND SATURATION
D/S = .6

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.2000	.1005	19.9551	.1000	.0508	25.8891
.1980	.0995	20.0400	.0980	.0498	26.0634
.1960	.0986	20.1259	.0960	.0487	26.2414
.1940	.0976	20.2127	.0940	.0477	26.4232
.1920	.0966	20.3005	.0920	.0467	26.6089
.1900	.0956	20.3892	.0900	.0457	26.7988
.1880	.0946	20.4789	.0880	.0447	26.9930
.1860	.0937	20.5697	.0860	.0437	27.1917
.1840	.0927	20.6614	.0840	.0427	27.3951
.1820	.0917	20.7542	.0820	.0417	27.6034
.1800	.0907	20.8481	.0800	.0407	27.8170
.1780	.0897	20.9431	.0780	.0396	28.0360
.1760	.0887	21.0392	.0760	.0386	28.2607
.1740	.0877	21.1364	.0740	.0376	28.4915
.1720	.0867	21.2348	.0720	.0366	28.7287
.1700	.0858	21.3344	.0700	.0356	28.9726
.1680	.0848	21.4353	.0680	.0346	29.2236
.1660	.0838	21.5374	.0660	.0336	29.4821
.1640	.0828	21.6407	.0640	.0326	29.7486
.1620	.0818	21.7454	.0620	.0315	30.0237
.1600	.0808	21.8515	.0600	.0305	30.3078
.1580	.0798	21.9589	.0580	.0295	30.6016
.1560	.0788	22.0677	.0560	.0285	30.9057
.1540	.0778	22.1780	.0540	.0275	31.2210
.1520	.0768	22.2898	.0520	.0265	31.5482
.1500	.0758	22.4031	.0500	.0254	31.8883
.1480	.0748	22.5180	.0480	.0244	32.2423
.1460	.0738	22.6345	.0460	.0234	32.6114
.1440	.0728	22.7526	.0440	.0224	32.9970
.1420	.0718	22.8724	.0420	.0214	33.4006
.1400	.0708	22.9940	.0400	.0204	33.8239
.1380	.0698	23.1174	.0380	.0193	34.2690
.1360	.0688	23.2426	.0360	.0183	34.7382
.1340	.0678	23.3698	.0340	.0173	35.2343
.1320	.0668	23.4988	.0320	.0163	35.7605
.1300	.0658	23.6300	.0300	.0153	36.3207
.1280	.0648	23.7631	.0280	.0143	36.9197
.1260	.0638	23.8985	.0260	.0132	37.5630
.1240	.0628	24.0360	.0240	.0122	38.2580
.1220	.0618	24.1758	.0220	.0112	39.0135
.1200	.0608	24.3180	.0200	.0102	39.8411
.1180	.0598	24.4626	.0180	.0092	40.7561
.1160	.0588	24.6098	.0160	.0081	41.7789
.1140	.0578	24.7595	.0140	.0071	42.9386
.1120	.0568	24.9120	.0120	.0061	44.2774
.1100	.0558	25.0672	.0100	.0051	45.8609
.1080	.0548	25.2253	.0080	.0041	47.7990
.1060	.0538	25.3865	.0060	.0031	50.2977
.1040	.0528	25.5507	.0040	.0020	53.8194
.1020	.0518	25.7182	.0020	.0010	59.8400

DEAD ZONE AND SATURATION
D/S = .8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	.1041	19.6520	.9000	.1328	17.5358
.9980	.1052	19.5593	.8980	.1331	17.5162
.9960	.1062	19.4744	.8960	.1334	17.4971
.9940	.1072	19.3947	.8940	.1337	17.4785
.9920	.1082	19.3192	.8920	.1340	17.4603
.9900	.1091	19.2471	.8900	.1342	17.4427
.9880	.1099	19.1781	.8880	.1345	17.4255
.9860	.1108	19.1119	.8860	.1348	17.4087
.9840	.1116	19.0483	.8840	.1350	17.3924
.9820	.1124	18.9869	.8820	.1353	17.3766
.9800	.1131	18.9277	.8800	.1355	17.3612
.9780	.1139	18.8705	.8780	.1357	17.3462
.9760	.1146	18.8152	.8760	.1360	17.3316
.9740	.1153	18.7616	.8740	.1362	17.3174
.9720	.1160	18.7097	.8720	.1364	17.3036
.9700	.1167	18.6594	.8700	.1366	17.2903
.9680	.1173	18.6106	.8680	.1368	17.2773
.9660	.1180	18.5632	.8660	.1370	17.2647
.9640	.1186	18.5171	.8640	.1372	17.2525
.9620	.1192	18.4724	.8620	.1374	17.2406
.9600	.1198	18.4289	.8600	.1376	17.2291
.9580	.1204	18.3866	.8580	.1378	17.2180
.9560	.1210	18.3454	.8560	.1379	17.2073
.9540	.1215	18.3054	.8540	.1381	17.1968
.9520	.1221	18.2664	.8520	.1382	17.1868
.9500	.1226	18.2284	.8500	.1384	17.1771
.9480	.1231	18.1915	.8480	.1386	17.1677
.9460	.1237	18.1554	.8460	.1387	17.1586
.9440	.1242	18.1203	.8440	.1388	17.1499
.9420	.1247	18.0861	.8420	.1390	17.1415
.9400	.1251	18.0528	.8400	.1391	17.1334
.9380	.1256	18.0203	.8380	.1392	17.1256
.9360	.1261	17.9886	.8360	.1393	17.1182
.9340	.1265	17.9578	.8340	.1395	17.1110
.9320	.1269	17.9277	.8320	.1396	17.1042
.9300	.1274	17.8983	.8300	.1397	17.0976
.9280	.1278	17.8697	.8280	.1398	17.0914
.9260	.1282	17.8417	.8260	.1399	17.0854
.9240	.1286	17.8145	.8240	.1400	17.0797
.9220	.1290	17.7879	.8220	.1401	17.0743
.9200	.1294	17.7620	.8200	.1401	17.0692
.9180	.1298	17.7368	.8180	.1402	17.0644
.9160	.1301	17.7121	.8160	.1403	17.0599
.9140	.1305	17.6881	.8140	.1404	17.0556
.9120	.1308	17.6646	.8120	.1404	17.0516
.9100	.1312	17.6418	.8100	.1405	17.0478
.9080	.1315	17.6195	.8080	.1405	17.0444
.9060	.1319	17.5978	.8060	.1406	17.0412
.9040	.1322	17.5766	.8040	.1406	17.0382
.9020	.1325	17.5559	.8020	.1407	17.0355

DEAD ZONE AND SATURATION

D/S = .8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.1407	17.0331	.7000	.1381	17.1950
.7980	.1408	17.0309	.6980	.1380	17.2033
.7960	.1408	17.0290	.6960	.1379	17.2118
.7940	.1408	17.0273	.6940	.1377	17.2205
.7920	.1408	17.0258	.6920	.1376	17.2293
.7900	.1409	17.0246	.6900	.1374	17.2384
.7880	.1409	17.0237	.6880	.1373	17.2476
.7860	.1409	17.0230	.6860	.1371	17.2570
.7840	.1409	17.0225	.6840	.1370	17.2666
.7820	.1409	17.0222	.6820	.1368	17.2763
.7800	.1409	17.0222	.6800	.1367	17.2862
.7780	.1409	17.0224	.6780	.1365	17.2964
.7760	.1409	17.0229	.6760	.1364	17.3067
.7740	.1409	17.0235	.6740	.1362	17.3171
.7720	.1409	17.0244	.6720	.1360	17.3278
.7700	.1408	17.0256	.6700	.1359	17.3386
.7680	.1408	17.0269	.6680	.1357	17.3496
.7660	.1408	17.0285	.6660	.1355	17.3607
.7640	.1408	17.0303	.6640	.1353	17.3721
.7620	.1407	17.0323	.6620	.1352	17.3836
.7600	.1407	17.0345	.6600	.1350	17.3953
.7580	.1407	17.0369	.6580	.1348	17.4072
.7560	.1406	17.0395	.6560	.1346	17.4192
.7540	.1406	17.0424	.6540	.1344	17.4314
.7520	.1405	17.0455	.6520	.1342	17.4438
.7500	.1405	17.0487	.6500	.1340	17.4563
.7480	.1404	17.0522	.6480	.1338	17.4691
.7460	.1403	17.0559	.6460	.1336	17.4820
.7440	.1403	17.0598	.6440	.1334	17.4950
.7420	.1402	17.0639	.6420	.1332	17.5083
.7400	.1401	17.0682	.6400	.1330	17.5217
.7380	.1401	17.0727	.6380	.1328	17.5353
.7360	.1400	17.0774	.6360	.1326	17.5490
.7340	.1399	17.0823	.6340	.1324	17.5630
.7320	.1398	17.0874	.6320	.1322	17.5771
.7300	.1398	17.0926	.6300	.1320	17.5913
.7280	.1397	17.0981	.6280	.1317	17.6058
.7260	.1396	17.1038	.6260	.1315	17.6204
.7240	.1395	17.1097	.6240	.1313	17.6352
.7220	.1394	17.1158	.6220	.1311	17.6501
.7200	.1393	17.1220	.6200	.1308	17.6652
.7180	.1392	17.1285	.6180	.1306	17.6805
.7160	.1391	17.1351	.6160	.1304	17.6960
.7140	.1390	17.1419	.6140	.1301	17.7116
.7120	.1389	17.1489	.6120	.1299	17.7274
.7100	.1387	17.1562	.6100	.1297	17.7434
.7080	.1386	17.1635	.6080	.1294	17.7595
.7060	.1385	17.1711	.6060	.1292	17.7758
.7040	.1384	17.1789	.6040	.1289	17.7923
.7020	.1382	17.1868	.6020	.1287	17.8090

DEAD ZONE AND SATURATION
D/S = .8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.1284	17.8258	.5000	.1136	18.8902
.5980	.1282	17.8428	.4980	.1133	18.9161
.5960	.1279	17.8600	.4960	.1130	18.9423
.5940	.1277	17.8773	.4940	.1126	18.9686
.5920	.1274	17.8948	.4920	.1123	18.9951
.5900	.1272	17.9125	.4900	.1119	19.0219
.5880	.1269	17.9303	.4880	.1116	19.0488
.5860	.1266	17.9483	.4860	.1112	19.0759
.5840	.1264	17.9665	.4840	.1109	19.1033
.5820	.1261	17.9849	.4820	.1105	19.1308
.5800	.1258	18.0034	.4800	.1102	19.1585
.5780	.1256	18.0221	.4780	.1098	19.1864
.5760	.1253	18.0410	.4760	.1095	19.2146
.5740	.1250	18.0601	.4740	.1091	19.2429
.5720	.1247	18.0793	.4720	.1087	19.2714
.5700	.1245	18.0987	.4700	.1084	19.3002
.5680	.1242	18.1183	.4680	.1080	19.3291
.5660	.1239	18.1380	.4660	.1077	19.3583
.5640	.1236	18.1579	.4640	.1073	19.3877
.5620	.1233	18.1780	.4620	.1069	19.4172
.5600	.1231	18.1983	.4600	.1066	19.4470
.5580	.1228	18.2188	.4580	.1062	19.4770
.5560	.1225	18.2394	.4560	.1058	19.5073
.5540	.1222	18.2602	.4540	.1055	19.5377
.5520	.1219	18.2812	.4520	.1051	19.5683
.5500	.1216	18.3023	.4500	.1047	19.5992
.5480	.1213	18.3236	.4480	.1043	19.6303
.5460	.1210	18.3451	.4460	.1040	19.6616
.5440	.1207	18.3668	.4440	.1036	19.6931
.5420	.1204	18.3887	.4420	.1032	19.7249
.5400	.1201	18.4107	.4400	.1028	19.7569
.5380	.1198	18.4330	.4380	.1025	19.7891
.5360	.1195	18.4554	.4360	.1021	19.8215
.5340	.1192	18.4780	.4340	.1017	19.8541
.5320	.1188	18.5007	.4320	.1013	19.8870
.5300	.1185	18.5237	.4300	.1009	19.9202
.5280	.1182	18.5468	.4280	.1005	19.9535
.5260	.1179	18.5701	.4260	.1001	19.9871
.5240	.1176	18.5936	.4240	.0998	20.0209
.5220	.1173	18.6173	.4220	.0994	20.0550
.5200	.1169	18.6412	.4200	.0990	20.0893
.5180	.1166	18.6652	.4180	.0986	20.1238
.5160	.1163	18.6895	.4160	.0982	20.1586
.5140	.1160	18.7139	.4140	.0978	20.1936
.5120	.1156	18.7385	.4120	.0974	20.2289
.5100	.1153	18.7633	.4100	.0970	20.2644
.5080	.1150	18.7883	.4080	.0966	20.3002
.5060	.1146	18.8135	.4060	.0962	20.3363
.5040	.1143	18.8389	.4040	.0958	20.3725
.5020	.1140	18.8644	.4020	.0954	20.4091

DEAD ZONE AND SATURATION

D/S = .8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.0950	20.4459	.3000	.0735	22.6690
.3980	.0946	20.4829	.2980	.0731	22.7226
.3960	.0942	20.5202	.2960	.0726	22.7765
.3940	.0938	20.5578	.2940	.0722	22.8309
.3920	.0934	20.5957	.2920	.0717	22.8858
.3900	.0930	20.6338	.2900	.0713	22.9410
.3880	.0926	20.6721	.2880	.0708	22.9968
.3860	.0921	20.7108	.2860	.0704	23.0529
.3840	.0917	20.7497	.2840	.0699	23.1096
.3820	.0913	20.7889	.2820	.0694	23.1667
.3800	.0909	20.8284	.2800	.0690	23.2243
.3780	.0905	20.8682	.2780	.0685	23.2823
.3760	.0901	20.9082	.2760	.0681	23.3409
.3740	.0897	20.9486	.2740	.0676	23.3999
.3720	.0892	20.9892	.2720	.0671	23.4594
.3700	.0888	21.0301	.2700	.0667	23.5194
.3680	.0884	21.0713	.2680	.0662	23.5800
.3660	.0880	21.1128	.2660	.0658	23.6410
.3640	.0876	21.1546	.2640	.0653	23.7026
.3620	.0871	21.1967	.2620	.0648	23.7647
.3600	.0867	21.2391	.2600	.0644	23.8274
.3580	.0863	21.2819	.2580	.0639	23.8906
.3560	.0859	21.3249	.2560	.0634	23.9543
.3540	.0854	21.3682	.2540	.0630	24.0187
.3520	.0850	21.4119	.2520	.0625	24.0835
.3500	.0846	21.4559	.2500	.0620	24.1490
.3480	.0841	21.5002	.2480	.0616	24.2151
.3460	.0837	21.5448	.2460	.0611	24.2817
.3440	.0833	21.5897	.2440	.0606	24.3490
.3420	.0828	21.6350	.2420	.0601	24.4169
.3400	.0824	21.6806	.2400	.0597	24.4854
.3380	.0820	21.7266	.2380	.0592	24.5545
.3360	.0815	21.7729	.2360	.0587	24.6243
.3340	.0811	21.8195	.2340	.0582	24.6948
.3320	.0807	21.8665	.2320	.0578	24.7659
.3300	.0802	21.9139	.2300	.0573	24.8377
.3280	.0798	21.9616	.2280	.0568	24.9101
.3260	.0793	22.0096	.2260	.0563	24.9833
.3240	.0789	22.0580	.2240	.0559	25.0572
.3220	.0785	22.1068	.2220	.0554	25.1318
.3200	.0780	22.1560	.2200	.0549	25.2072
.3180	.0776	22.2055	.2180	.0544	25.2833
.3160	.0771	22.2555	.2160	.0540	25.3602
.3140	.0767	22.3058	.2140	.0535	25.4378
.3120	.0762	22.3564	.2120	.0530	25.5162
.3100	.0758	22.4075	.2100	.0525	25.5955
.3080	.0753	22.4590	.2080	.0520	25.6755
.3060	.0749	22.5109	.2060	.0515	25.7564
.3040	.0744	22.5632	.2040	.0511	25.8382
.3020	.0740	22.6159	.2020	.0506	25.9208

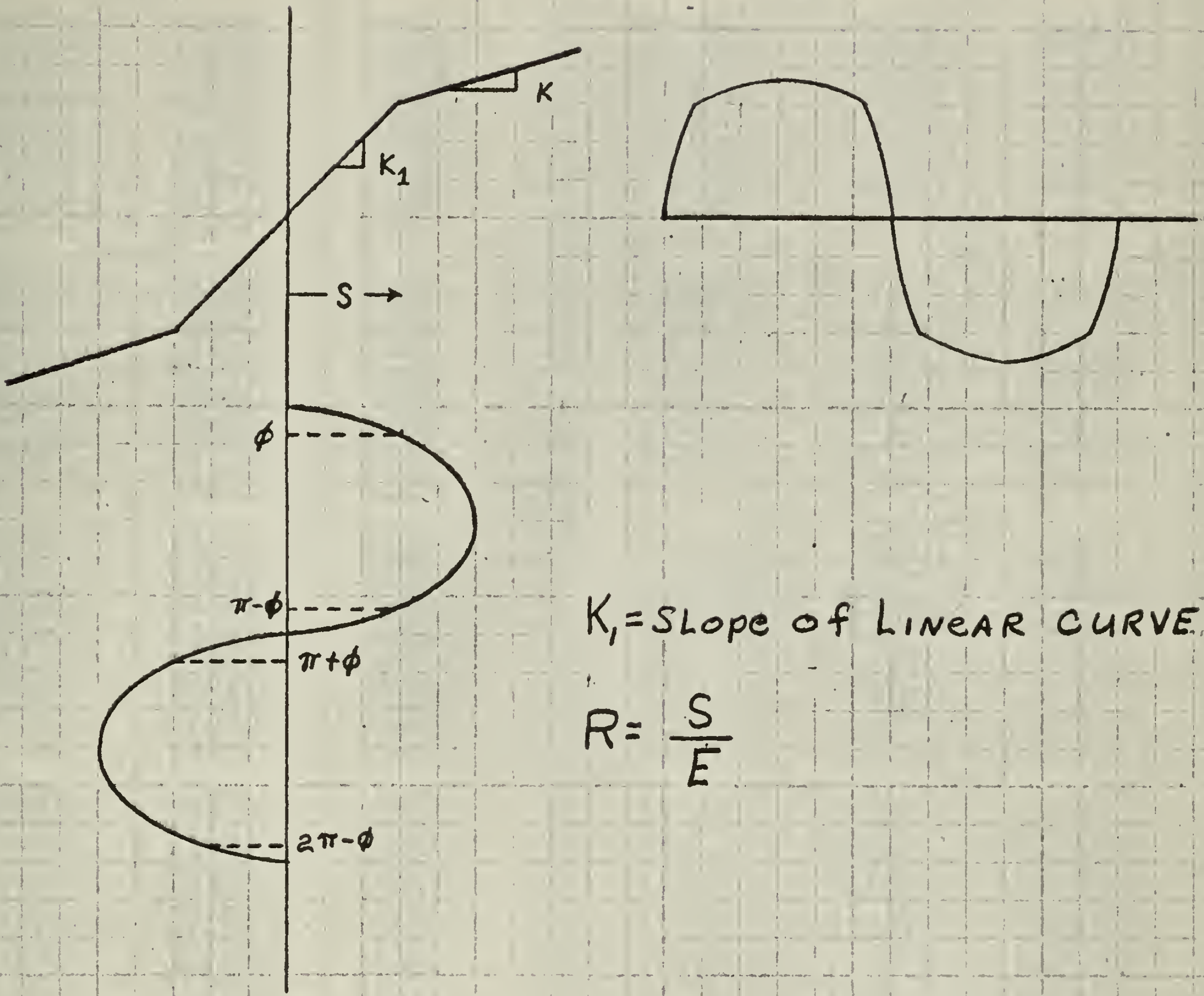
DEAD ZONE AND SATURATION
D/S = .8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.2000	.0501	26.0043	.1000	.0254	31.9167
.1980	.0496	26.0886	.0980	.0249	32.0907
.1960	.0491	26.1739	.0960	.0244	32.2684
.1940	.0486	26.2602	.0940	.0239	32.4500
.1920	.0482	26.3474	.0920	.0233	32.6354
.1900	.0477	26.4356	.0900	.0228	32.8250
.1880	.0472	26.5247	.0880	.0223	33.0190
.1860	.0467	26.6149	.0860	.0218	33.2174
.1840	.0462	26.7061	.0840	.0213	33.4206
.1820	.0457	26.7984	.0820	.0208	33.6287
.1800	.0452	26.8917	.0800	.0203	33.8421
.1780	.0447	26.9862	.0780	.0198	34.0608
.1760	.0442	27.0818	.0760	.0193	34.2854
.1740	.0438	27.1785	.0740	.0188	34.5159
.1720	.0433	27.2764	.0720	.0183	34.7529
.1700	.0428	27.3755	.0700	.0178	34.9966
.1680	.0423	27.4759	.0680	.0173	35.2474
.1660	.0418	27.5775	.0660	.0168	35.5057
.1640	.0413	27.6804	.0640	.0163	35.7721
.1620	.0408	27.7846	.0620	.0158	36.0470
.1600	.0403	27.8902	.0600	.0153	36.3309
.1580	.0398	27.9971	.0580	.0147	36.6245
.1560	.0393	28.1055	.0560	.0142	36.9285
.1540	.0388	28.2154	.0540	.0137	37.2436
.1520	.0383	28.3267	.0520	.0132	37.5707
.1500	.0378	28.4396	.0500	.0127	37.9106
.1480	.0374	28.5540	.0480	.0122	38.2645
.1460	.0369	28.6701	.0460	.0117	38.6335
.1440	.0364	28.7878	.0440	.0112	39.0190
.1420	.0359	28.9072	.0420	.0107	39.4224
.1400	.0354	29.0284	.0400	.0102	39.8456
.1380	.0349	29.1514	.0380	.0097	40.2906
.1360	.0344	29.2762	.0360	.0092	40.7597
.1340	.0339	29.4030	.0340	.0087	41.2557
.1320	.0334	29.5317	.0320	.0081	41.7818
.1300	.0329	29.6624	.0300	.0076	42.3419
.1280	.0324	29.7953	.0280	.0071	42.9408
.1260	.0319	29.9302	.0260	.0066	43.5841
.1240	.0314	30.0674	.0240	.0061	44.2790
.1220	.0309	30.2069	.0220	.0056	45.0344
.1200	.0304	30.3487	.0200	.0051	45.8620
.1180	.0299	30.4930	.0180	.0046	46.7769
.1160	.0294	30.6398	.0160	.0041	47.7997
.1140	.0289	30.7892	.0140	.0036	48.9593
.1120	.0284	30.9414	.0120	.0031	50.2981
.1100	.0279	31.0963	.0100	.0025	51.8815
.1080	.0274	31.2541	.0080	.0020	53.8196
.1060	.0269	31.4149	.0060	.0015	56.3183
.1040	.0264	31.5789	.0040	.0010	59.8400
.1020	.0259	31.7461	.0020	.0005	65.8606

APPENDIX XIV

Saturation

Saturation occurs in almost every electronic amplifier. In general there is no sharp breakpoint between linear and nonlinear operation, but an approximate breakpoint can usually be chosen with small resultant error. If a higher degree of accuracy is required the characteristic curve can be broken into several linear portions and a new describing function developed. Several runs of data were obtained from Program DESCRIB for various values of gain of the saturation portion of the characteristic curve.



K_1 = Slope of Linear Curve

$$R = \frac{S}{E}$$

Figure XIV
Saturation

SATURATION K=.0

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	1.0000	.0000	.9000	.9626	.3310
.9980	.9999	.0010	.8980	.9615	.3410
.9960	.9997	.0027	.8960	.9604	.3512
.9940	.9994	.0049	.8940	.9592	.3615
.9920	.9991	.0075	.8920	.9581	.3719
.9900	.9988	.0104	.8900	.9569	.3824
.9880	.9984	.0137	.8880	.9558	.3930
.9860	.9980	.0173	.8860	.9546	.4037
.9840	.9976	.0211	.8840	.9534	.4144
.9820	.9971	.0252	.8820	.9522	.4253
.9800	.9966	.0295	.8800	.9510	.4363
.9780	.9961	.0340	.8780	.9498	.4474
.9760	.9956	.0387	.8760	.9486	.4586
.9740	.9950	.0437	.8740	.9473	.4699
.9720	.9944	.0488	.8720	.9461	.4813
.9700	.9938	.0541	.8700	.9448	.4928
.9680	.9932	.0596	.8680	.9436	.5044
.9660	.9925	.0653	.8660	.9423	.5161
.9640	.9918	.0711	.8640	.9410	.5279
.9620	.9912	.0772	.8620	.9397	.5398
.9600	.9905	.0833	.8600	.9385	.5517
.9580	.9897	.0897	.8580	.9371	.5638
.9560	.9890	.0961	.8560	.9358	.5760
.9540	.9882	.1028	.8540	.9345	.5883
.9520	.9875	.1096	.8520	.9332	.6006
.9500	.9867	.1165	.8500	.9319	.6131
.9480	.9859	.1236	.8480	.9305	.6256
.9460	.9851	.1308	.8460	.9292	.6383
.9440	.9842	.1381	.8440	.9278	.6510
.9420	.9834	.1456	.8420	.9264	.6638
.9400	.9825	.1532	.8400	.9250	.6768
.9380	.9816	.1610	.8380	.9237	.6898
.9360	.9807	.1688	.8360	.9223	.7029
.9340	.9798	.1768	.8340	.9209	.7161
.9320	.9789	.1850	.8320	.9195	.7294
.9300	.9780	.1932	.8300	.9180	.7428
.9280	.9771	.2016	.8280	.9166	.7563
.9260	.9761	.2101	.8260	.9152	.7699
.9240	.9751	.2187	.8240	.9137	.7835
.9220	.9742	.2274	.8220	.9123	.7973
.9200	.9732	.2363	.8200	.9108	.8111
.9180	.9722	.2452	.8180	.9094	.8251
.9160	.9711	.2543	.8160	.9079	.8391
.9140	.9701	.2635	.8140	.9064	.8533
.9120	.9691	.2728	.8120	.9050	.8675
.9100	.9680	.2822	.8100	.9035	.8818
.9080	.9670	.2918	.8080	.9020	.8962
.9060	.9659	.3014	.8060	.9005	.9107
.9040	.9648	.3112	.8040	.8990	.9253
.9020	.9637	.3210	.8020	.8974	.9399

```
                        SATURATION       K=.0
    R          GD     1/GD(DB)              R          GD     1/GD(DB)

  .8000      .8959      .9547             .7000      .8119     1.8102
  .7980      .8944      .9696             .6980      .8101     1.8297
  .7960      .8928      .9845             .6960      .8082     1.8493
  .7940      .8913      .9996             .6940      .8064     1.8690
  .7920      .8897     1.0147             .6920      .8046     1.8888
  .7900      .8882     1.0299             .6900      .8027     1.9087
  .7880      .8866     1.0452             .6880      .8009     1.9287
  .7860      .8851     1.0606             .6860      .7990     1.9488
  .7840      .8835     1.0761             .6840      .7972     1.9690
  .7820      .8819     1.0917             .6820      .7953     1.9892

  .7800      .8803     1.1074             .6800      .7934     2.0096
  .7780      .8787     1.1232             .6780      .7916     2.0301
  .7760      .8771     1.1390             .6760      .7897     2.0507
  .7740      .8755     1.1550             .6740      .7878     2.0714
  .7720      .8739     1.1710             .6720      .7859     2.0922
  .7700      .8723     1.1872             .6700      .7841     2.1131
  .7680      .8706     1.2034             .6680      .7822     2.1341
  .7660      .8690     1.2197             .6660      .7803     2.1552
  .7640      .8674     1.2361             .6640      .7784     2.1764
  .7620      .8657     1.2526             .6620      .7765     2.1977

  .7600      .8641     1.2692             .6600      .7745     2.2191
  .7580      .8624     1.2859             .6580      .7726     2.2406
  .7560      .8607     1.3026             .6560      .7707     2.2622
  .7540      .8591     1.3195             .6540      .7688     2.2839
  .7520      .8574     1.3365             .6520      .7669     2.3057
  .7500      .8557     1.3535             .6500      .7649     2.3276
  .7480      .8540     1.3707             .6480      .7630     2.3497
  .7460      .8523     1.3879             .6460      .7610     2.3718
  .7440      .8506     1.4052             .6440      .7591     2.3940
  .7420      .8489     1.4227             .6420      .7571     2.4164

  .7400      .8472     1.4402             .6400      .7552     2.4388
  .7380      .8455     1.4578             .6380      .7532     2.4614
  .7360      .8438     1.4755             .6360      .7513     2.4841
  .7340      .8420     1.4933             .6340      .7493     2.5068
  .7320      .8403     1.5112             .6320      .7473     2.5297
  .7300      .8386     1.5291             .6300      .7454     2.5527
  .7280      .8368     1.5472             .6280      .7434     2.5758
  .7260      .8351     1.5654             .6260      .7414     2.5990
  .7240      .8333     1.5836             .6240      .7394     2.6223
  .7220      .8316     1.6020             .6220      .7374     2.6458

  .7200      .8298     1.6204             .6200      .7354     2.6693
  .7180      .8280     1.6390             .6180      .7334     2.6930
  .7160      .8263     1.6576             .6160      .7314     2.7167
  .7140      .8245     1.6764             .6140      .7294     2.7406
  .7120      .8227     1.6952             .6120      .7274     2.7646
  .7100      .8209     1.7141             .6100      .7254     2.7887
  .7080      .8191     1.7331             .6080      .7234     2.8129
  .7060      .8173     1.7523             .6060      .7213     2.8373
  .7040      .8155     1.7715             .6040      .7193     2.8617
  .7020      .8137     1.7908             .6020      .7173     2.8863
```

SATURATION K=.0

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.7152	2.9109	.5000	.6090	4.3077
.5980	.7132	2.9357	.4980	.6068	4.3392
.5960	.7112	2.9607	.4960	.6046	4.3709
.5940	.7091	2.9857	.4940	.6024	4.4028
.5920	.7071	3.0108	.4920	.6002	4.4348
.5900	.7050	3.0361	.4900	.5979	4.4669
.5880	.7030	3.0615	.4880	.5957	4.4993
.5860	.7009	3.0870	.4860	.5935	4.5318
.5840	.6988	3.1127	.4840	.5913	4.5644
.5820	.6968	3.1384	.4820	.5890	4.5972
.5800	.6947	3.1643	.4800	.5868	4.6302
.5780	.6926	3.1903	.4780	.5846	4.6634
.5760	.6905	3.2164	.4760	.5823	4.6967
.5740	.6884	3.2426	.4740	.5801	4.7302
.5720	.6864	3.2690	.4720	.5778	4.7638
.5700	.6843	3.2955	.4700	.5756	4.7977
.5680	.6822	3.3221	.4680	.5733	4.8317
.5660	.6801	3.3489	.4660	.5711	4.8659
.5640	.6780	3.3758	.4640	.5688	4.9002
.5620	.6759	3.4028	.4620	.5666	4.9347
.5600	.6738	3.4299	.4600	.5643	4.9695
.5580	.6716	3.4572	.4580	.5621	5.0043
.5560	.6695	3.4846	.4560	.5598	5.0394
.5540	.6674	3.5121	.4540	.5575	5.0747
.5520	.6653	3.5397	.4520	.5553	5.1101
.5500	.6632	3.5675	.4500	.5530	5.1457
.5480	.6610	3.5954	.4480	.5507	5.1816
.5460	.6589	3.6235	.4460	.5484	5.2176
.5440	.6568	3.6517	.4440	.5462	5.2537
.5420	.6546	3.6800	.4420	.5439	5.2901
.5400	.6525	3.7085	.4400	.5416	5.3267
.5380	.6503	3.7371	.4380	.5393	5.3635
.5360	.6482	3.7658	.4360	.5370	5.4004
.5340	.6460	3.7947	.4340	.5347	5.4376
.5320	.6439	3.8237	.4320	.5324	5.4750
.5300	.6417	3.8529	.4300	.5301	5.5126
.5280	.6396	3.8822	.4280	.5278	5.5503
.5260	.6374	3.9116	.4260	.5255	5.5883
.5240	.6352	3.9412	.4240	.5232	5.6265
.5220	.6331	3.9709	.4220	.5209	5.6649
.5200	.6309	4.0008	.4200	.5186	5.7035
.5180	.6287	4.0308	.4180	.5163	5.7423
.5160	.6265	4.0610	.4160	.5140	5.7813
.5140	.6244	4.0913	.4140	.5116	5.8206
.5120	.6222	4.1218	.4120	.5093	5.8600
.5100	.6200	4.1524	.4100	.5070	5.8997
.5080	.6178	4.1831	.4080	.5047	5.9396
.5060	.6156	4.2140	.4060	.5024	5.9797
.5040	.6134	4.2451	.4040	.5000	6.0201
.5020	.6112	4.2763	.4020	.4977	6.0606

```
                         SATURATION         K=.0
  R          GD     1/GD(DB)              R         GD     1/GD(DB)

.4000      .4954     6.1015             .3000     .3762     8.4925
.3980      .4930     6.1425             .2980     .3737     8.5488
.3960      .4907     6.1838             .2960     .3713     8.6055
.3940      .4884     6.2253             .2940     .3689     8.6626
.3920      .4860     6.2670             .2920     .3664     8.7201
.3900      .4837     6.3090             .2900     .3640     8.7781
.3880      .4813     6.3512             .2880     .3616     8.8364
.3860      .4790     6.3937             .2860     .3591     8.8952
.3840      .4766     6.4364             .2840     .3567     8.9545
.3820      .4743     6.4794             .2820     .3542     9.0142

.3800      .4719     6.5226             .2800     .3518     9.0743
.3780      .4696     6.5661             .2780     .3493     9.1349
.3760      .4672     6.6099             .2760     .3469     9.1959
.3740      .4648     6.6539             .2740     .3445     9.2574
.3720      .4625     6.6981             .2720     .3420     9.3194
.3700      .4601     6.7426             .2700     .3396     9.3819
.3680      .4577     6.7874             .2680     .3371     9.4449
.3660      .4554     6.8325             .2660     .3346     9.5084
.3640      .4530     6.8778             .2640     .3322     9.5723
.3620      .4506     6.9235             .2620     .3297     9.6368

.3600      .4483     6.9694             .2600     .3273     9.7018
.3580      .4459     7.0155             .2580     .3248     9.7673
.3560      .4435     7.0620             .2560     .3224     9.8334
.3540      .4411     7.1087             .2540     .3199     9.9000
.3520      .4387     7.1558             .2520     .3174     9.9671
.3500      .4364     7.2031             .2500     .3150    10.0348
.3480      .4340     7.2507             .2480     .3125    10.1031
.3460      .4316     7.2987             .2460     .3100    10.1720
.3440      .4292     7.3469             .2440     .3076    10.2414
.3420      .4268     7.3955             .2420     .3051    10.3115

.3400      .4244     7.4443             .2400     .3026    10.3821
.3380      .4220     7.4935             .2380     .3001    10.4534
.3360      .4196     7.5430             .2360     .2977    10.5253
.3340      .4172     7.5928             .2340     .2952    10.5978
.3320      .4148     7.6429             .2320     .2927    10.6710
.3300      .4124     7.6934             .2300     .2902    10.7448
.3280      .4100     7.7442             .2280     .2878    10.8193
.3260      .4076     7.7953             .2260     .2853    10.8945
.3240      .4052     7.8468             .2240     .2828    10.9704
.3220      .4028     7.8986             .2220     .2803    11.0469

.3200      .4004     7.9507             .2200     .2778    11.1242
.3180      .3980     8.0033             .2180     .2754    11.2023
.3160      .3955     8.0561             .2160     .2729    11.2810
.3140      .3931     8.1094             .2140     .2704    11.3606
.3120      .3907     8.1630             .2120     .2679    11.4409
.3100      .3883     8.2169             .2100     .2654    11.5219
.3080      .3859     8.2713             .2080     .2629    11.6038
.3060      .3834     8.3260             .2060     .2604    11.6865
.3040      .3810     8.3811             .2040     .2579    11.7701
.3020      .3786     8.4366             .2020     .2554    11.8544
```

SATURATION K=.0

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.2000	.2529	11.9397	.1000	.1271	17.9163
.1980	.2504	12.0258	.0980	.1246	18.0912
.1960	.2479	12.1128	.0960	.1220	18.2698
.1940	.2454	12.2008	.0940	.1195	18.4521
.1920	.2430	12.2896	.0920	.1170	18.6383
.1900	.2405	12.3795	.0900	.1144	18.8287
.1880	.2380	12.4703	.0880	.1119	19.0234
.1860	.2354	12.5621	.0860	.1094	19.2226
.1840	.2329	12.6549	.0840	.1068	19.4265
.1820	.2304	12.7487	.0820	.1043	19.6353
.1800	.2279	12.8436	.0800	.1018	19.8493
.1780	.2254	12.9396	.0780	.0992	20.0687
.1760	.2229	13.0367	.0760	.0967	20.2939
.1740	.2204	13.1350	.0740	.0941	20.5251
.1720	.2179	13.2344	.0720	.0916	20.7627
.1700	.2154	13.3350	.0700	.0891	21.0070
.1680	.2129	13.4368	.0680	.0865	21.2583
.1660	.2104	13.5398	.0660	.0840	21.5173
.1640	.2079	13.6441	.0640	.0814	21.7842
.1620	.2054	13.7497	.0620	.0789	22.0596
.1600	.2028	13.8567	.0600	.0763	22.3440
.1580	.2003	13.9650	.0580	.0738	22.6381
.1560	.1978	14.0748	.0560	.0713	22.9426
.1540	.1953	14.1859	.0540	.0687	23.2582
.1520	.1928	14.2986	.0520	.0662	23.5857
.1500	.1903	14.4127	.0500	.0636	23.9260
.1480	.1877	14.5285	.0480	.0611	24.2803
.1460	.1852	14.6458	.0460	.0585	24.6497
.1440	.1827	14.7647	.0440	.0560	25.0356
.1420	.1802	14.8854	.0420	.0535	25.4394
.1400	.1777	15.0078	.0400	.0509	25.8629
.1380	.1751	15.1319	.0380	.0484	26.3082
.1360	.1726	15.2579	.0360	.0458	26.7776
.1340	.1701	15.3858	.0340	.0433	27.2739
.1320	.1676	15.5157	.0320	.0407	27.8003
.1300	.1651	15.6475	.0300	.0382	28.3607
.1280	.1625	15.7814	.0280	.0356	28.9598
.1260	.1600	15.9175	.0260	.0331	29.6033
.1240	.1575	16.0557	.0240	.0306	30.2984
.1220	.1549	16.1962	.0220	.0280	31.0541
.1200	.1524	16.3391	.0200	.0255	31.8818
.1180	.1499	16.4844	.0180	.0229	32.7968
.1160	.1474	16.6322	.0160	.0204	33.8198
.1140	.1448	16.7826	.0140	.0178	34.9795
.1120	.1423	16.9357	.0120	.0153	36.3184
.1100	.1398	17.0915	.0100	.0127	37.9020
.1080	.1372	17.2503	.0080	.0102	39.8401
.1060	.1347	17.4120	.0060	.0076	42.3388
.1040	.1322	17.5768	.0040	.0051	45.8605
.1020	.1296	17.7449	.0020	.0025	51.8812

SATURATION K=.2

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	1.0000	.0000	.9000	.9701	.2638
.9980	.9999	.0008	.8980	.9692	.2718
.9960	.9998	.0021	.8960	.9683	.2798
.9940	.9996	.0039	.8940	.9674	.2880
.9920	.9993	.0060	.8920	.9665	.2962
.9900	.9990	.0083	.8900	.9655	.3045
.9880	.9987	.0110	.8880	.9646	.3129
.9860	.9984	.0138	.8860	.9637	.3214
.9840	.9981	.0169	.8840	.9627	.3300
.9820	.9977	.0201	.8820	.9618	.3386
.9800	.9973	.0236	.8800	.9608	.3473
.9780	.9969	.0272	.8780	.9598	.3561
.9760	.9964	.0310	.8760	.9589	.3650
.9740	.9960	.0349	.8740	.9579	.3739
.9720	.9955	.0390	.8720	.9569	.3829
.9700	.9950	.0433	.8700	.9559	.3920
.9680	.9945	.0477	.8680	.9549	.4012
.9660	.9940	.0522	.8660	.9539	.4104
.9640	.9935	.0569	.8640	.9528	.4197
.9620	.9929	.0617	.8620	.9518	.4291
.9600	.9924	.0666	.8600	.9508	.4386
.9580	.9918	.0717	.8580	.9497	.4481
.9560	.9912	.0768	.8560	.9487	.4577
.9540	.9906	.0821	.8540	.9476	.4674
.9520	.9900	.0875	.8520	.9466	.4771
.9500	.9893	.0931	.8500	.9455	.4870
.9480	.9887	.0987	.8480	.9444	.4968
.9460	.9880	.1045	.8460	.9433	.5068
.9440	.9874	.1103	.8440	.9422	.5168
.9420	.9867	.1163	.8420	.9411	.5270
.9400	.9860	.1224	.8400	.9400	.5371
.9380	.9853	.1285	.8380	.9389	.5474
.9360	.9846	.1348	.8360	.9378	.5577
.9340	.9839	.1412	.8340	.9367	.5681
.9320	.9831	.1477	.8320	.9356	.5785
.9300	.9824	.1542	.8300	.9344	.5891
.9280	.9816	.1609	.8280	.9333	.5997
.9260	.9809	.1677	.8260	.9321	.6103
.9240	.9801	.1745	.8240	.9310	.6211
.9220	.9793	.1815	.8220	.9298	.6319
.9200	.9785	.1885	.8200	.9287	.6427
.9180	.9777	.1956	.8180	.9275	.6537
.9160	.9769	.2029	.8160	.9263	.6647
.9140	.9761	.2102	.8140	.9251	.6758
.9120	.9753	.2176	.8120	.9240	.6869
.9100	.9744	.2251	.8100	.9228	.6981
.9080	.9736	.2326	.8080	.9216	.7094
.9060	.9727	.2403	.8060	.9204	.7207
.9040	.9718	.2480	.8040	.9192	.7322
.9020	.9710	.2559	.8020	.9179	.7436

SATURATION K=.2

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.9167	.7552	.7000	.8495	1.4167
.7980	.9155	.7668	.6980	.8480	1.4316
.7960	.9143	.7785	.6960	.8466	1.4466
.7940	.9130	.7902	.6940	.8451	1.4616
.7920	.9118	.8021	.6920	.8437	1.4767
.7900	.9105	.8139	.6900	.8422	1.4919
.7880	.9093	.8259	.6880	.8407	1.5072
.7860	.9080	.8379	.6860	.8392	1.5225
.7840	.9068	.8500	.6840	.8377	1.5378
.7820	.9055	.8621	.6820	.8362	1.5533
.7800	.9042	.8743	.6800	.8348	1.5688
.7780	.9030	.8866	.6780	.8333	1.5844
.7760	.9017	.8990	.6760	.8318	1.6000
.7740	.9004	.9114	.6740	.8303	1.6157
.7720	.8991	.9238	.6720	.8288	1.6315
.7700	.8978	.9364	.6700	.8272	1.6473
.7680	.8965	.9490	.6680	.8257	1.6633
.7660	.8952	.9617	.6660	.8242	1.6792
.7640	.8939	.9744	.6640	.8227	1.6953
.7620	.8926	.9872	.6620	.8212	1.7114
.7600	.8912	1.0001	.6600	.8196	1.7276
.7580	.8899	1.0130	.6580	.8181	1.7438
.7560	.8886	1.0260	.6560	.8166	1.7602
.7540	.8872	1.0391	.6540	.8150	1.7765
.7520	.8859	1.0522	.6520	.8135	1.7930
.7500	.8846	1.0654	.6500	.8119	1.8095
.7480	.8832	1.0787	.6480	.8104	1.8261
.7460	.8819	1.0920	.6460	.8088	1.8428
.7440	.8805	1.1054	.6440	.8073	1.8595
.7420	.8791	1.1189	.6420	.8057	1.8763
.7400	.8778	1.1324	.6400	.8042	1.8932
.7380	.8764	1.1460	.6380	.8026	1.9101
.7360	.8750	1.1596	.6360	.8010	1.9272
.7340	.8736	1.1734	.6340	.7994	1.9442
.7320	.8723	1.1872	.6320	.7979	1.9614
.7300	.8709	1.2010	.6300	.7963	1.9786
.7280	.8695	1.2149	.6280	.7947	1.9959
.7260	.8681	1.2289	.6260	.7931	2.0133
.7240	.8667	1.2430	.6240	.7915	2.0307
.7220	.8653	1.2571	.6220	.7899	2.0482
.7200	.8638	1.2713	.6200	.7883	2.0658
.7180	.8624	1.2855	.6180	.7867	2.0834
.7160	.8610	1.2998	.6160	.7851	2.1011
.7140	.8596	1.3142	.6140	.7835	2.1189
.7120	.8582	1.3287	.6120	.7819	2.1368
.7100	.8567	1.3432	.6100	.7803	2.1547
.7080	.8553	1.3577	.6080	.7787	2.1727
.7060	.8538	1.3724	.6060	.7771	2.1908
.7040	.8524	1.3871	.6040	.7754	2.2090
.7020	.8510	1.4019	.6020	.7738	2.2272

SATURATION K=.2

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.7722	2.2455	.5000	.6872	3.2584
.5980	.7706	2.2639	.4980	.6854	3.2807
.5960	.7689	2.2823	.4960	.6837	3.3031
.5940	.7673	2.3008	.4940	.6819	3.3257
.5920	.7656	2.3194	.4920	.6801	3.3483
.5900	.7640	2.3381	.4900	.6783	3.3710
.5880	.7624	2.3568	.4880	.6766	3.3937
.5860	.7607	2.3756	.4860	.6748	3.4166
.5840	.7591	2.3945	.4840	.6730	3.4396
.5820	.7574	2.4135	.4820	.6712	3.4626
.5800	.7557	2.4325	.4800	.6694	3.4858
.5780	.7541	2.4516	.4780	.6677	3.5090
.5760	.7524	2.4708	.4760	.6659	3.5323
.5740	.7508	2.4900	.4740	.6641	3.5558
.5720	.7491	2.5094	.4720	.6623	3.5793
.5700	.7474	2.5288	.4700	.6605	3.6029
.5680	.7457	2.5483	.4680	.6587	3.6266
.5660	.7441	2.5679	.4660	.6569	3.6503
.5640	.7424	2.5875	.4640	.6551	3.6742
.5620	.7407	2.6072	.4620	.6533	3.6982
.5600	.7390	2.6270	.4600	.6515	3.7223
.5580	.7373	2.6469	.4580	.6496	3.7464
.5560	.7356	2.6669	.4560	.6478	3.7707
.5540	.7339	2.6869	.4540	.6460	3.7951
.5520	.7322	2.7070	.4520	.6442	3.8195
.5500	.7305	2.7272	.4500	.6424	3.8441
.5480	.7288	2.7475	.4480	.6406	3.8687
.5460	.7271	2.7678	.4460	.6387	3.8934
.5440	.7254	2.7882	.4440	.6369	3.9183
.5420	.7237	2.8087	.4420	.6351	3.9432
.5400	.7220	2.8293	.4400	.6333	3.9683
.5380	.7203	2.8500	.4380	.6314	3.9934
.5360	.7186	2.8707	.4360	.6296	4.0187
.5340	.7168	2.8916	.4340	.6278	4.0440
.5320	.7151	2.9125	.4320	.6259	4.0694
.5300	.7134	2.9335	.4300	.6241	4.0950
.5280	.7117	2.9545	.4280	.6223	4.1206
.5260	.7099	2.9757	.4260	.6204	4.1464
.5240	.7082	2.9969	.4240	.6186	4.1723
.5220	.7065	3.0183	.4220	.6167	4.1982
.5200	.7047	3.0397	.4200	.6149	4.2243
.5180	.7030	3.0612	.4180	.6130	4.2504
.5160	.7012	3.0827	.4160	.6112	4.2767
.5140	.6995	3.1044	.4140	.6093	4.3031
.5120	.6977	3.1261	.4120	.6075	4.3296
.5100	.6960	3.1480	.4100	.6056	4.3562
.5080	.6942	3.1699	.4080	.6037	4.3829
.5060	.6925	3.1919	.4060	.6019	4.4097
.5040	.6907	3.2139	.4040	.6000	4.4366
.5020	.6890	3.2361	.4020	.5982	4.4637

SATURATION K=.2

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.5963	4.4908	.3000	.5009	6.0045
.3980	.5944	4.5180	.2980	.4990	6.0382
.3960	.5926	4.5454	.2960	.4970	6.0722
.3940	.5907	4.5729	.2940	.4951	6.1063
.3920	.5888	4.6005	.2920	.4931	6.1405
.3900	.5869	4.6282	.2900	.4912	6.1749
.3880	.5851	4.6560	.2880	.4892	6.2094
.3860	.5832	4.6839	.2860	.4873	6.2442
.3840	.5813	4.7120	.2840	.4853	6.2790
.3820	.5794	4.7401	.2820	.4834	6.3141
.3800	.5775	4.7684	.2800	.4814	6.3493
.3780	.5757	4.7968	.2780	.4795	6.3846
.3760	.5738	4.8253	.2760	.4775	6.4202
.3740	.5719	4.8540	.2740	.4756	6.4559
.3720	.5700	4.8827	.2720	.4736	6.4917
.3700	.5681	4.9116	.2700	.4716	6.5278
.3680	.5662	4.9406	.2680	.4697	6.5640
.3660	.5643	4.9697	.2660	.4677	6.6004
.3640	.5624	4.9990	.2640	.4658	6.6369
.3620	.5605	5.0283	.2620	.4638	6.6737
.3600	.5586	5.0578	.2600	.4618	6.7106
.3580	.5567	5.0874	.2580	.4599	6.7477
.3560	.5548	5.1172	.2560	.4579	6.7849
.3540	.5529	5.1470	.2540	.4559	6.8224
.3520	.5510	5.1770	.2520	.4539	6.8600
.3500	.5491	5.2072	.2500	.4520	6.8978
.3480	.5472	5.2374	.2480	.4500	6.9358
.3460	.5453	5.2678	.2460	.4480	6.9740
.3440	.5434	5.2983	.2440	.4460	7.0124
.3420	.5414	5.3290	.2420	.4441	7.0510
.3400	.5395	5.3597	.2400	.4421	7.0897
.3380	.5376	5.3906	.2380	.4401	7.1287
.3360	.5357	5.4217	.2360	.4381	7.1678
.3340	.5338	5.4529	.2340	.4362	7.2072
.3320	.5319	5.4842	.2320	.4342	7.2467
.3300	.5299	5.5156	.2300	.4322	7.2864
.3280	.5280	5.5472	.2280	.4302	7.3264
.3260	.5261	5.5789	.2260	.4282	7.3665
.3240	.5242	5.6108	.2240	.4262	7.4069
.3220	.5222	5.6428	.2220	.4243	7.4475
.3200	.5203	5.6750	.2200	.4223	7.4882
.3180	.5184	5.7073	.2180	.4203	7.5292
.3160	.5164	5.7397	.2160	.4183	7.5704
.3140	.5145	5.7723	.2140	.4163	7.6118
.3120	.5126	5.8050	.2120	.4143	7.6534
.3100	.5106	5.8379	.2100	.4123	7.6953
.3080	.5087	5.8709	.2080	.4103	7.7374
.3060	.5068	5.9041	.2060	.4083	7.7797
.3040	.5048	5.9374	.2040	.4063	7.8222
.3020	.5029	5.9709	.2020	.4043	7.8649

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                             SATURATION       K=.2
    R           GD      1/GD(DB)              R           GD      1/GD(DB)

  .2000       .4024      7.9079             .1000       .3017     10.4088
  .1980       .4004      7.9511             .0980       .2997     10.4674
  .1960       .3984      7.9945             .0960       .2976     10.5263
  .1940       .3964      8.0382             .0940       .2956     10.5857
  .1920       .3944      8.0821             .0920       .2936     10.6455
  .1900       .3924      8.1263             .0900       .2915     10.7058
  .1880       .3904      8.1707             .0880       .2895     10.7664
  .1860       .3884      8.2153             .0860       .2875     10.8275
  .1840       .3864      8.2602             .0840       .2855     10.8891
  .1820       .3844      8.3054             .0820       .2834     10.9511

  .1800       .3824      8.3508             .0800       .2814     11.0135
  .1780       .3803      8.3964             .0780       .2794     11.0764
  .1760       .3783      8.4423             .0760       .2773     11.1398
  .1740       .3763      8.4885             .0740       .2753     11.2037
  .1720       .3743      8.5349             .0720       .2733     11.2680
  .1700       .3723      8.5816             .0700       .2712     11.3328
  .1680       .3703      8.6286             .0680       .2692     11.3982
  .1660       .3683      8.6758             .0660       .2672     11.4640
  .1640       .3663      8.7233             .0640       .2651     11.5303
  .1620       .3643      8.7711             .0620       .2631     11.5972

  .1600       .3623      8.8192             .0600       .2611     11.6646
  .1580       .3603      8.8676             .0580       .2590     11.7325
  .1560       .3583      8.9162             .0560       .2570     11.8010
  .1540       .3562      8.9651             .0540       .2550     11.8700
  .1520       .3542      9.0144             .0520       .2529     11.9396
  .1500       .3522      9.0639             .0500       .2509     12.0097
  .1480       .3502      9.1137             .0480       .2489     12.0804
  .1460       .3482      9.1638             .0460       .2468     12.1517
  .1440       .3462      9.2143             .0440       .2448     12.2236
  .1420       .3442      9.2650             .0420       .2428     12.2962

  .1400       .3421      9.3160             .0400       .2407     12.3693
  .1380       .3401      9.3674             .0380       .2387     12.4431
  .1360       .3381      9.4191             .0360       .2367     12.5175
  .1340       .3361      9.4711             .0340       .2346     12.5925
  .1320       .3341      9.5235             .0320       .2326     12.6682
  .1300       .3320      9.5761             .0300       .2306     12.7446
  .1280       .3300      9.6291             .0280       .2285     12.8216
  .1260       .3280      9.6825             .0260       .2265     12.8994
  .1240       .3260      9.7362             .0240       .2244     12.9778
  .1220       .3240      9.7902             .0220       .2224     13.0570

  .1200       .3219      9.8446             .0200       .2204     13.1369
  .1180       .3199      9.8993             .0180       .2183     13.2176
  .1160       .3179      9.9544             .0160       .2163     13.2990
  .1140       .3159     10.0099             .0140       .2143     13.3812
  .1120       .3138     10.0657             .0120       .2122     13.4642
  .1100       .3118     10.1220             .0100       .2102     13.5479
  .1080       .3098     10.1786             .0080       .2081     13.6325
  .1060       .3078     10.2355             .0060       .2061     13.7180
  .1040       .3057     10.2929             .0040       .2041     13.8042
  .1020       .3037     10.3507             .0020       .2020     13.8914
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SATURATION K=.4

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	1.0000	.0000	.9000	.9776	.1971
.9980	.9999	.0006	.8980	.9769	.2030
.9960	.9998	.0016	.8960	.9762	.2090
.9940	.9997	.0029	.8940	.9755	.2151
.9920	.9995	.0045	.8920	.9749	.2212
.9900	.9993	.0063	.8900	.9742	.2274
.9880	.9991	.0082	.8880	.9735	.2336
.9860	.9988	.0104	.8860	.9728	.2399
.9840	.9985	.0127	.8840	.9720	.2463
.9820	.9983	.0151	.8820	.9713	.2527
.9800	.9980	.0177	.8800	.9706	.2592
.9780	.9977	.0204	.8780	.9699	.2657
.9760	.9973	.0232	.8760	.9691	.2723
.9740	.9970	.0262	.8740	.9684	.2789
.9720	.9966	.0292	.8720	.9677	.2856
.9700	.9963	.0324	.8700	.9669	.2923
.9680	.9959	.0357	.8680	.9661	.2991
.9660	.9955	.0391	.8660	.9654	.3060
.9640	.9951	.0426	.8640	.9646	.3129
.9620	.9947	.0462	.8620	.9638	.3198
.9600	.9943	.0499	.8600	.9631	.3268
.9580	.9938	.0537	.8580	.9623	.3339
.9560	.9934	.0576	.8560	.9615	.3410
.9540	.9929	.0615	.8540	.9607	.3482
.9520	.9925	.0656	.8520	.9599	.3554
.9500	.9920	.0697	.8500	.9591	.3626
.9480	.9915	.0739	.8480	.9583	.3699
.9460	.9910	.0782	.8460	.9575	.3773
.9440	.9905	.0826	.8440	.9567	.3847
.9420	.9900	.0871	.8420	.9559	.3922
.9400	.9895	.0916	.8400	.9550	.3997
.9380	.9890	.0962	.8380	.9542	.4073
.9360	.9884	.1009	.8360	.9534	.4149
.9340	.9879	.1057	.8340	.9525	.4225
.9320	.9874	.1105	.8320	.9517	.4303
.9300	.9868	.1154	.8300	.9508	.4380
.9280	.9862	.1204	.8280	.9500	.4458
.9260	.9857	.1254	.8260	.9491	.4537
.9240	.9851	.1306	.8240	.9482	.4616
.9220	.9845	.1357	.8220	.9474	.4695
.9200	.9839	.1410	.8200	.9465	.4775
.9180	.9833	.1463	.8180	.9456	.4856
.9160	.9827	.1517	.8160	.9447	.4937
.9140	.9821	.1572	.8140	.9439	.5018
.9120	.9814	.1627	.8120	.9430	.5100
.9100	.9808	.1682	.8100	.9421	.5183
.9080	.9802	.1739	.8080	.9412	.5265
.9060	.9795	.1796	.8060	.9403	.5349
.9040	.9789	.1854	.8040	.9394	.5433
.9020	.9782	.1912	.8020	.9385	.5517

SATURATION K=.4

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.9375	.5601	.7000	.8871	1.0403
.7980	.9366	.5687	.6980	.8860	1.0510
.7960	.9357	.5772	.6960	.8849	1.0617
.7940	.9348	.5858	.6940	.8838	1.0725
.7920	.9338	.5945	.6920	.8827	1.0834
.7900	.9329	.6032	.6900	.8816	1.0942
.7880	.9320	.6119	.6880	.8805	1.1052
.7860	.9310	.6207	.6860	.8794	1.1161
.7840	.9301	.6296	.6840	.8783	1.1271
.7820	.9291	.6384	.6820	.8772	1.1382
.7800	.9282	.6474	.6800	.8761	1.1492
.7780	.9272	.6563	.6780	.8749	1.1604
.7760	.9263	.6653	.6760	.8738	1.1715
.7740	.9253	.6744	.6740	.8727	1.1828
.7720	.9243	.6835	.6720	.8716	1.1940
.7700	.9234	.6927	.6700	.8704	1.2053
.7680	.9224	.7018	.6680	.8693	1.2166
.7660	.9214	.7111	.6660	.8682	1.2280
.7640	.9204	.7204	.6640	.8670	1.2394
.7620	.9194	.7297	.6620	.8659	1.2509
.7600	.9184	.7391	.6600	.8647	1.2624
.7580	.9174	.7485	.6580	.8636	1.2740
.7560	.9164	.7579	.6560	.8624	1.2856
.7540	.9154	.7674	.6540	.8613	1.2972
.7520	.9144	.7770	.6520	.8601	1.3089
.7500	.9134	.7866	.6500	.8590	1.3206
.7480	.9124	.7962	.6480	.8578	1.3324
.7460	.9114	.8059	.6460	.8566	1.3442
.7440	.9104	.8156	.6440	.8555	1.3560
.7420	.9094	.8254	.6420	.8543	1.3679
.7400	.9083	.8352	.6400	.8531	1.3798
.7380	.9073	.8450	.6380	.8519	1.3918
.7360	.9063	.8549	.6360	.8508	1.4038
.7340	.9052	.8648	.6340	.8496	1.4159
.7320	.9042	.8748	.6320	.8484	1.4280
.7300	.9031	.8848	.6300	.8472	1.4401
.7280	.9021	.8949	.6280	.8460	1.4523
.7260	.9011	.9050	.6260	.8448	1.4645
.7240	.9000	.9152	.6240	.8436	1.4768
.7220	.8989	.9253	.6220	.8424	1.4891
.7200	.8979	.9356	.6200	.8413	1.5015
.7180	.8968	.9459	.6180	.8401	1.5139
.7160	.8958	.9562	.6160	.8388	1.5263
.7140	.8947	.9665	.6140	.8376	1.5388
.7120	.8936	.9770	.6120	.8364	1.5513
.7100	.8925	.9874	.6100	.8352	1.5639
.7080	.8915	.9979	.6080	.8340	1.5765
.7060	.8904	1.0084	.6060	.8328	1.5892
.7040	.8893	1.0190	.6040	.8316	1.6019
.7020	.8882	1.0296	.6020	.8304	1.6146

SATURATION K=.4

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.8291	1.6274	.5000	.7654	2.3223
.5980	.8279	1.6402	.4980	.7641	2.3373
.5960	.8267	1.6531	.4960	.7627	2.3524
.5940	.8255	1.6660	.4940	.7614	2.3675
.5920	.8242	1.6790	.4920	.7601	2.3827
.5900	.8230	1.6920	.4900	.7588	2.3979
.5880	.8218	1.7050	.4880	.7574	2.4132
.5860	.8205	1.7181	.4860	.7561	2.4285
.5840	.8193	1.7312	.4840	.7548	2.4439
.5820	.8181	1.7444	.4820	.7534	2.4593
.5800	.8168	1.7576	.4800	.7521	2.4747
.5780	.8156	1.7708	.4780	.7507	2.4902
.5760	.8143	1.7841	.4760	.7494	2.5058
.5740	.8131	1.7975	.4740	.7481	2.5214
.5720	.8118	1.8109	.4720	.7467	2.5370
.5700	.8106	1.8243	.4700	.7454	2.5527
.5680	.8093	1.8378	.4680	.7440	2.5685
.5660	.8080	1.8513	.4660	.7427	2.5842
.5640	.8068	1.8649	.4640	.7413	2.6001
.5620	.8055	1.8785	.4620	.7399	2.6160
.5600	.8043	1.8921	.4600	.7386	2.6319
.5580	.8030	1.9058	.4580	.7372	2.6479
.5560	.8017	1.9195	.4560	.7359	2.6639
.5540	.8004	1.9333	.4540	.7345	2.6800
.5520	.7992	1.9472	.4520	.7332	2.6961
.5500	.7979	1.9610	.4500	.7318	2.7123
.5480	.7966	1.9749	.4480	.7304	2.7285
.5460	.7953	1.9889	.4460	.7291	2.7447
.5440	.7941	2.0029	.4440	.7277	2.7611
.5420	.7928	2.0169	.4420	.7263	2.7774
.5400	.7915	2.0310	.4400	.7249	2.7938
.5380	.7902	2.0452	.4380	.7236	2.8103
.5360	.7889	2.0593	.4360	.7222	2.8268
.5340	.7876	2.0736	.4340	.7208	2.8434
.5320	.7863	2.0878	.4320	.7194	2.8600
.5300	.7850	2.1021	.4300	.7181	2.8767
.5280	.7837	2.1165	.4280	.7167	2.8934
.5260	.7824	2.1309	.4260	.7153	2.9101
.5240	.7811	2.1454	.4240	.7139	2.9269
.5220	.7798	2.1598	.4220	.7125	2.9438
.5200	.7785	2.1744	.4200	.7112	2.9607
.5180	.7772	2.1890	.4180	.7098	2.9777
.5160	.7759	2.2036	.4160	.7084	2.9947
.5140	.7746	2.2183	.4140	.7070	3.0117
.5120	.7733	2.2330	.4120	.7056	3.0289
.5100	.7720	2.2477	.4100	.7042	3.0460
.5080	.7707	2.2626	.4080	.7028	3.0632
.5060	.7694	2.2774	.4060	.7014	3.0805
.5040	.7680	2.2923	.4040	.7000	3.0978
.5020	.7667	2.3073	.4020	.6986	3.1152

SATURATION K=.4

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.6972	3.1326	.3000	.6257	4.0727
.3980	.6958	3.1501	.2980	.6242	4.0930
.3960	.6944	3.1676	.2960	.6228	4.1133
.3940	.6930	3.1852	.2940	.6213	4.1337
.3920	.6916	3.2028	.2920	.6199	4.1541
.3900	.6902	3.2205	.2900	.6184	4.1746
.3880	.6888	3.2382	.2880	.6169	4.1952
.3860	.6874	3.2560	.2860	.6155	4.2158
.3840	.6860	3.2738	.2840	.6140	4.2365
.3820	.6846	3.2917	.2820	.6125	4.2573
.3800	.6832	3.3097	.2800	.6111	4.2781
.3780	.6817	3.3277	.2780	.6096	4.2990
.3760	.6803	3.3457	.2760	.6081	4.3199
.3740	.6789	3.3638	.2740	.6067	4.3409
.3720	.6775	3.3820	.2720	.6052	4.3620
.3700	.6761	3.4002	.2700	.6037	4.3831
.3680	.6746	3.4184	.2680	.6023	4.4043
.3660	.6732	3.4368	.2660	.6008	4.4256
.3640	.6718	3.4551	.2640	.5993	4.4469
.3620	.6704	3.4735	.2620	.5978	4.4683
.3600	.6690	3.4920	.2600	.5964	4.4898
.3580	.6675	3.5106	.2580	.5949	4.5113
.3560	.6661	3.5292	.2560	.5934	4.5329
.3540	.6647	3.5478	.2540	.5919	4.5545
.3520	.6632	3.5665	.2520	.5905	4.5763
.3500	.6618	3.5853	.2500	.5890	4.5980
.3480	.6604	3.6041	.2480	.5875	4.6199
.3460	.6590	3.6229	.2460	.5860	4.6418
.3440	.6575	3.6419	.2440	.5845	4.6638
.3420	.6561	3.6608	.2420	.5831	4.6858
.3400	.6546	3.6799	.2400	.5816	4.7080
.3380	.6532	3.6990	.2380	.5801	4.7301
.3360	.6518	3.7181	.2360	.5786	4.7524
.3340	.6503	3.7373	.2340	.5771	4.7747
.3320	.6489	3.7566	.2320	.5756	4.7971
.3300	.6474	3.7759	.2300	.5741	4.8196
.3280	.6460	3.7953	.2280	.5727	4.8421
.3260	.6446	3.8147	.2260	.5712	4.8647
.3240	.6431	3.8342	.2240	.5697	4.8874
.3220	.6417	3.8538	.2220	.5682	4.9101
.3200	.6402	3.8734	.2200	.5667	4.9329
.3180	.6388	3.8930	.2180	.5652	4.9558
.3160	.6373	3.9128	.2160	.5637	4.9787
.3140	.6359	3.9326	.2140	.5622	5.0018
.3120	.6344	3.9524	.2120	.5607	5.0249
.3100	.6330	3.9723	.2100	.5592	5.0480
.3080	.6315	3.9923	.2080	.5577	5.0713
.3060	.6301	4.0123	.2060	.5563	5.0946
.3040	.6286	4.0324	.2040	.5548	5.1180
.3020	.6272	4.0525	.2020	.5533	5.1414

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                     SATURATION        K=.4
  R          GD     1/GD(DB)              R           GD      1/GD(DB)

.2000      .5518    5.1649             .1000        .4763      6.4430
.1980      .5503    5.1885             .0980        .4747      6.4708
.1960      .5488    5.2122             .0960        .4732      6.4986
.1940      .5473    5.2360             .0940        .4717      6.5266
.1920      .5458    5.2598             .0920        .4702      6.5547
.1900      .5443    5.2837             .0900        .4687      6.5828
.1880      .5428    5.3077             .0880        .4671      6.6111
.1860      .5413    5.3317             .0860        .4656      6.6394
.1840      .5398    5.3559             .0840        .4641      6.6679
.1820      .5383    5.3801             .0820        .4626      6.6964

.1800      .5368    5.4043             .0800        .4611      6.7250
.1780      .5353    5.4287             .0780        .4595      6.7538
.1760      .5338    5.4531             .0760        .4580      6.7826
.1740      .5323    5.4777             .0740        .4565      6.8116
.1720      .5307    5.5022             .0720        .4550      6.8406
.1700      .5292    5.5269             .0700        .4534      6.8698
.1680      .5277    5.5517             .0680        .4519      6.8990
.1660      .5262    5.5765             .0660        .4504      6.9283
.1640      .5247    5.6014             .0640        .4489      6.9578
.1620      .5232    5.6264             .0620        .4473      6.9874

.1600      .5217    5.6515             .0600        .4458      7.0170
.1580      .5202    5.6766             .0580        .4443      7.0468
.1560      .5187    5.7018             .0560        .4428      7.0767
.1540      .5172    5.7272             .0540        .4412      7.1066
.1520      .5157    5.7526             .0520        .4397      7.1367
.1500      .5142    5.7780             .0500        .4382      7.1669
.1480      .5126    5.8036             .0480        .4367      7.1972
.1460      .5111    5.8292             .0460        .4351      7.2276
.1440      .5096    5.8550             .0440        .4336      7.2582
.1420      .5081    5.8808             .0420        .4321      7.2888

.1400      .5066    5.9067             .0400        .4305      7.3195
.1380      .5051    5.9327             .0380        .4290      7.3504
.1360      .5036    5.9587             .0360        .4275      7.3814
.1340      .5021    5.9849             .0340        .4260      7.4124
.1320      .5005    6.0111             .0320        .4244      7.4436
.1300      .4990    6.0374             .0300        .4229      7.4749
.1280      .4975    6.0638             .0280        .4214      7.5064
.1260      .4960    6.0903             .0260        .4199      7.5379
.1240      .4945    6.1169             .0240        .4183      7.5696
.1220      .4930    6.1436             .0220        .4168      7.6013

.1200      .4915    6.1704             .0200        .4153      7.6332
.1180      .4899    6.1972             .0180        .4138      7.6652
.1160      .4884    6.2242             .0160        .4122      7.6974
.1140      .4869    6.2512             .0140        .4107      7.7296
.1120      .4854    6.2783             .0120        .4092      7.7620
.1100      .4839    6.3055             .0100        .4076      7.7945
.1080      .4823    6.3328             .0080        .4061      7.8271
.1060      .4808    6.3602             .0060        .4046      7.8598
.1040      .4793    6.3877             .0040        .4031      7.8927
.1020      .4778    6.4153             .0020        .4015      7.9257
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                         SATURATION          K=.6
      R           GD     1/GD(DB)                R          GD     1/GD(DB)

   1.0000      1.0000      .0000              .9000       .9850      .1309
    .9980      1.0000      .0004              .8980       .9846      .1348
    .9960       .9999      .0011              .8960       .9841      .1388
    .9940       .9998      .0019              .8940       .9837      .1428
    .9920       .9997      .0030              .8920       .9832      .1468
    .9900       .9995      .0042              .8900       .9828      .1509
    .9880       .9994      .0055              .8880       .9823      .1551
    .9860       .9992      .0069              .8860       .9818      .1592
    .9840       .9990      .0084              .8840       .9814      .1634
    .9820       .9988      .0101              .8820       .9809      .1675

    .9800       .9986      .0118              .8800       .9804      .1719
    .9780       .9984      .0136              .8780       .9799      .1762
    .9760       .9982      .0155              .8760       .9794      .1806
    .9740       .9980      .0174              .8740       .9789      .1849
    .9720       .9978      .0195              .8720       .9784      .1893
    .9700       .9975      .0216              .8700       .9779      .1938
    .9680       .9973      .0238              .8680       .9774      .1983
    .9660       .9970      .0261              .8660       .9769      .2028
    .9640       .9967      .0284              .8640       .9764      .2073
    .9620       .9965      .0308              .8620       .9759      .2119

    .9600       .9962      .0332              .8600       .9754      .2165
    .9580       .9959      .0358              .8580       .9749      .2212
    .9560       .9956      .0383              .8560       .9743      .2258
    .9540       .9953      .0410              .8540       .9738      .2305
    .9520       .9950      .0437              .8520       .9733      .2353
    .9500       .9947      .0464              .8500       .9727      .2401
    .9480       .9943      .0492              .8480       .9722      .2449
    .9460       .9940      .0521              .8460       .9717      .2497
    .9440       .9937      .0550              .8440       .9711      .2546
    .9420       .9934      .0579              .8420       .9706      .2595

    .9400       .9930      .0610              .8400       .9700      .2644
    .9380       .9927      .0640              .8380       .9695      .2694
    .9360       .9923      .0671              .8360       .9689      .2744
    .9340       .9919      .0703              .8340       .9683      .2794
    .9320       .9916      .0735              .8320       .9678      .2845
    .9300       .9912      .0768              .8300       .9672      .2895
    .9280       .9908      .0801              .8280       .9666      .2947
    .9260       .9904      .0834              .8260       .9661      .2998
    .9240       .9901      .0868              .8240       .9655      .3050
    .9220       .9897      .0903              .8220       .9649      .3102

    .9200       .9893      .0937              .8200       .9643      .3154
    .9180       .9889      .0973              .8180       .9638      .3207
    .9160       .9885      .1008              .8160       .9632      .3260
    .9140       .9880      .1045              .8140       .9626      .3313
    .9120       .9876      .1081              .8120       .9620      .3367
    .9100       .9872      .1118              .8100       .9614      .3420
    .9080       .9868      .1155              .8080       .9608      .3475
    .9060       .9864      .1193              .8060       .9602      .3529
    .9040       .9859      .1231              .8040       .9596      .3584
    .9020       .9855      .1270              .8020       .9590      .3639
```

SATURATION K=.6

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.9584	.3694	.7000	.9248	.6795
.7980	.9578	.3749	.6980	.9240	.6863
.7960	.9571	.3805	.6960	.9233	.6932
.7940	.9565	.3861	.6940	.9226	.7001
.7920	.9559	.3918	.6920	.9218	.7070
.7900	.9553	.3974	.6900	.9211	.7140
.7880	.9546	.4031	.6880	.9204	.7209
.7860	.9540	.4088	.6860	.9196	.7279
.7840	.9534	.4146	.6840	.9189	.7349
.7820	.9528	.4204	.6820	.9181	.7420
.7800	.9521	.4262	.6800	.9174	.7490
.7780	.9515	.4320	.6780	.9166	.7561
.7760	.9508	.4379	.6760	.9159	.7632
.7740	.9502	.4437	.6740	.9151	.7703
.7720	.9495	.4496	.6720	.9144	.7775
.7700	.9489	.4556	.6700	.9136	.7847
.7680	.9483	.4615	.6680	.9129	.7919
.7660	.9476	.4675	.6660	.9121	.7991
.7640	.9469	.4735	.6640	.9113	.8063
.7620	.9463	.4796	.6620	.9106	.8136
.7600	.9456	.4857	.6600	.9098	.8209
.7580	.9450	.4917	.6580	.9091	.8282
.7560	.9443	.4979	.6560	.9083	.8356
.7540	.9436	.5040	.6540	.9075	.8429
.7520	.9430	.5102	.6520	.9067	.8503
.7500	.9423	.5164	.6500	.9060	.8577
.7480	.9416	.5226	.6480	.9052	.8652
.7460	.9409	.5289	.6460	.9044	.8726
.7440	.9403	.5351	.6440	.9036	.8801
.7420	.9396	.5414	.6420	.9029	.8876
.7400	.9389	.5478	.6400	.9021	.8951
.7380	.9382	.5541	.6380	.9013	.9027
.7360	.9375	.5605	.6360	.9005	.9102
.7340	.9368	.5669	.6340	.8997	.9178
.7320	.9361	.5733	.6320	.8989	.9255
.7300	.9354	.5798	.6300	.8981	.9331
.7280	.9347	.5862	.6280	.8974	.9408
.7260	.9340	.5927	.6260	.8966	.9484
.7240	.9333	.5993	.6240	.8958	.9561
.7220	.9326	.6058	.6220	.8950	.9639
.7200	.9319	.6124	.6200	.8942	.9716
.7180	.9312	.6190	.6180	.8934	.9794
.7160	.9305	.6256	.6160	.8926	.9872
.7140	.9298	.6323	.6140	.8918	.9950
.7120	.9291	.6389	.6120	.8910	1.0029
.7100	.9284	.6456	.6100	.8902	1.0107
.7080	.9276	.6524	.6080	.8893	1.0186
.7060	.9269	.6591	.6060	.8885	1.0265
.7040	.9262	.6659	.6040	.8877	1.0344
.7020	.9255	.6727	.6020	.8869	1.0424

```
                          SATURATION         K=.6
   R            GD     1/GD(DB)                    R           GD      1/GD(DB)

 .6000        .8861     1.0504                   .5000       .8436      1.4773
 .5980        .8853     1.0584                   .4980       .8427      1.4864
 .5960        .8845     1.0664                   .4960       .8418      1.4955
 .5940        .8836     1.0744                   .4940       .8409      1.5046
 .5920        .8828     1.0825                   .4920       .8401      1.5138
 .5900        .8820     1.0906                   .4900       .8392      1.5230
 .5880        .8812     1.0987                   .4880       .8383      1.5322
 .5860        .8804     1.1068                   .4860       .8374      1.5414
 .5840        .8795     1.1150                   .4840       .8365      1.5506
 .5820        .8787     1.1232                   .4820       .8356      1.5599

 .5800        .8779     1.1314                   .4800       .8347      1.5692
 .5780        .8770     1.1396                   .4780       .8338      1.5785
 .5760        .8762     1.1478                   .4760       .8329      1.5878
 .5740        .8754     1.1561                   .4740       .8320      1.5972
 .5720        .8745     1.1644                   .4720       .8311      1.6066
 .5700        .8737     1.1727                   .4700       .8302      1.6159
 .5680        .8729     1.1810                   .4680       .8293      1.6254
 .5660        .8720     1.1894                   .4660       .8284      1.6348
 .5640        .8712     1.1978                   .4640       .8275      1.6443
 .5620        .8703     1.2062                   .4620       .8266      1.6537

 .5600        .8695     1.2146                   .4600       .8257      1.6632
 .5580        .8687     1.2230                   .4580       .8248      1.6728
 .5560        .8678     1.2315                   .4560       .8239      1.6823
 .5540        .8670     1.2400                   .4540       .8230      1.6919
 .5520        .8661     1.2485                   .4520       .8221      1.7015
 .5500        .8653     1.2570                   .4500       .8212      1.7111
 .5480        .8644     1.2655                   .4480       .8203      1.7207
 .5460        .8636     1.2741                   .4460       .8194      1.7304
 .5440        .8627     1.2827                   .4440       .8185      1.7400
 .5420        .8619     1.2913                   .4420       .8175      1.7497

 .5400        .8610     1.3000                   .4400       .8166      1.7595
 .5380        .8601     1.3086                   .4380       .8157      1.7692
 .5360        .8593     1.3173                   .4360       .8148      1.7790
 .5340        .8584     1.3260                   .4340       .8139      1.7887
 .5320        .8576     1.3347                   .4320       .8130      1.7985
 .5300        .8567     1.3435                   .4300       .8120      1.8084
 .5280        .8558     1.3522                   .4280       .8111      1.8182
 .5260        .8550     1.3610                   .4260       .8102      1.8281
 .5240        .8541     1.3699                   .4240       .8093      1.8380
 .5220        .8532     1.3787                   .4220       .8084      1.8479

 .5200        .8524     1.3875                   .4200       .8074      1.8573
 .5180        .8515     1.3964                   .4180       .8065      1.8678
 .5160        .8506     1.4053                   .4160       .8056      1.8778
 .5140        .8497     1.4142                   .4140       .8047      1.8878
 .5120        .8489     1.4232                   .4120       .8037      1.8973
 .5100        .8480     1.4321                   .4100       .8028      1.9078
 .5080        .8471     1.4411                   .4080       .8019      1.9179
 .5060        .8462     1.4501                   .4060       .8009      1.9280
 .5040        .8454     1.4592                   .4040       .8000      1.9381
 .5020        .8445     1.4682                   .4020       .7991      1.9482
```

SATURATION K=.6

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.7981	1.9583	.3000	.7505	2.4934
.3980	.7972	1.9685	.2980	.7495	2.5047
.3960	.7963	1.9787	.2960	.7485	2.5159
.3940	.7953	1.9889	.2940	.7475	2.5272
.3920	.7944	1.9992	.2920	.7466	2.5386
.3900	.7935	2.0094	.2900	.7456	2.5499
.3880	.7925	2.0197	.2880	.7446	2.5613
.3860	.7916	2.0300	.2860	.7436	2.5727
.3840	.7907	2.0403	.2840	.7427	2.5841
.3820	.7897	2.0507	.2820	.7417	2.5955
.3800	.7888	2.0610	.2800	.7407	2.6070
.3780	.7878	2.0714	.2780	.7397	2.6184
.3760	.7869	2.0818	.2760	.7388	2.6299
.3740	.7859	2.0922	.2740	.7378	2.6415
.3720	.7850	2.1027	.2720	.7368	2.6530
.3700	.7840	2.1132	.2700	.7358	2.6646
.3680	.7831	2.1237	.2680	.7348	2.6762
.3660	.7822	2.1342	.2660	.7339	2.6878
.3640	.7812	2.1447	.2640	.7329	2.6994
.3620	.7803	2.1553	.2620	.7319	2.7111
.3600	.7793	2.1659	.2600	.7309	2.7227
.3580	.7784	2.1765	.2580	.7299	2.7344
.3560	.7774	2.1871	.2560	.7289	2.7462
.3540	.7765	2.1977	.2540	.7280	2.7579
.3520	.7755	2.2084	.2520	.7270	2.7697
.3500	.7745	2.2191	.2500	.7260	2.7815
.3480	.7736	2.2298	.2480	.7250	2.7933
.3460	.7726	2.2405	.2460	.7240	2.8051
.3440	.7717	2.2513	.2440	.7230	2.8170
.3420	.7707	2.2621	.2420	.7220	2.8288
.3400	.7698	2.2729	.2400	.7210	2.8407
.3380	.7688	2.2837	.2380	.7201	2.8527
.3360	.7678	2.2945	.2360	.7191	2.8646
.3340	.7669	2.3054	.2340	.7181	2.8766
.3320	.7659	2.3163	.2320	.7171	2.8886
.3300	.7650	2.3272	.2300	.7161	2.9006
.3280	.7640	2.3381	.2280	.7151	2.9126
.3260	.7630	2.3490	.2260	.7141	2.9247
.3240	.7621	2.3600	.2240	.7131	2.9367
.3220	.7611	2.3710	.2220	.7121	2.9488
.3200	.7601	2.3820	.2200	.7111	2.9610
.3180	.7592	2.3931	.2180	.7101	2.9731
.3160	.7582	2.4041	.2160	.7091	2.9853
.3140	.7573	2.4152	.2140	.7082	2.9975
.3120	.7563	2.4263	.2120	.7072	3.0097
.3100	.7553	2.4374	.2100	.7062	3.0219
.3080	.7543	2.4486	.2080	.7052	3.0342
.3060	.7534	2.4598	.2060	.7042	3.0465
.3040	.7524	2.4709	.2040	.7032	3.0588
.3020	.7514	2.4822	.2020	.7022	3.0711

```
                              SATURATION         K=.6
   R            GD      1/GD(DB)              R            GD      1/GD(DB)

 .2000        .7012      3.0835             .1000        .6508      3.7305
 .1980        .7002      3.0958             .0980        .6498      3.7440
 .1960        .6992      3.1082             .0960        .6488      3.7576
 .1940        .6982      3.1207             .0940        .6478      3.7711
 .1920        .6972      3.1331             .0920        .6468      3.7847
 .1900        .6962      3.1456             .0900        .6458      3.7984
 .1880        .6952      3.1581             .0880        .6448      3.8120
 .1860        .6942      3.1706             .0860        .6437      3.8257
 .1840        .6932      3.1831             .0840        .6427      3.8394
 .1820        .6922      3.1957             .0820        .6417      3.8532

 .1800        .6912      3.2082             .0800        .6407      3.8669
 .1780        .6902      3.2208             .0780        .6397      3.8807
 .1760        .6892      3.2335             .0760        .6387      3.8945
 .1740        .6882      3.2461             .0740        .6377      3.9083
 .1720        .6872      3.2588             .0720        .6366      3.9222
 .1700        .6862      3.2715             .0700        .6356      3.9360
 .1680        .6852      3.2842             .0680        .6346      3.9499
 .1660        .6842      3.2969             .0660        .6336      3.9638
 .1640        .6831      3.3097             .0640        .6326      3.9778
 .1620        .6821      3.3225             .0620        .6316      3.9918

 .1600        .6811      3.3353             .0600        .6305      4.0058
 .1580        .6801      3.3481             .0580        .6295      4.0198
 .1560        .6791      3.3610             .0560        .6285      4.0338
 .1540        .6781      3.3739             .0540        .6275      4.0479
 .1520        .6771      3.3868             .0520        .6265      4.0620
 .1500        .6761      3.3997             .0500        .6255      4.0761
 .1480        .6751      3.4126             .0480        .6244      4.0902
 .1460        .6741      3.4256             .0460        .6234      4.1044
 .1440        .6731      3.4386             .0440        .6224      4.1186
 .1420        .6721      3.4516             .0420        .6214      4.1328

 .1400        .6711      3.4647             .0400        .6204      4.1470
 .1380        .6701      3.4777             .0380        .6193      4.1613
 .1360        .6690      3.4908             .0360        .6183      4.1756
 .1340        .6680      3.5039             .0340        .6173      4.1899
 .1320        .6670      3.5171             .0320        .6163      4.2042
 .1300        .6660      3.5302             .0300        .6153      4.2186
 .1280        .6650      3.5434             .0280        .6143      4.2330
 .1260        .6640      3.5566             .0260        .6132      4.2474
 .1240        .6630      3.5699             .0240        .6122      4.2618
 .1220        .6620      3.5831             .0220        .6112      4.2763

 .1200        .6610      3.5964             .0200        .6102      4.2908
 .1180        .6600      3.6097             .0180        .6092      4.3053
 .1160        .6589      3.6230             .0160        .6081      4.3198
 .1140        .6579      3.6364             .0140        .6071      4.3344
 .1120        .6569      3.6497             .0120        .6061      4.3490
 .1100        .6559      3.6631             .0100        .6051      4.3636
 .1080        .6549      3.6765             .0080        .6041      4.3782
 .1060        .6539      3.6900             .0060        .6031      4.3929
 .1040        .6529      3.7035             .0040        .6020      4.4075
 .1020        .6519      3.7169             .0020        .6010      4.4222
```

SATURATION K=.8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
1.0000	1.0000	.0000	.9000	.9925	.0652
.9980	1.0000	.0002	.8980	.9923	.0671
.9960	.9999	.0005	.8960	.9921	.0691
.9940	.9999	.0010	.8940	.9918	.0711
.9920	.9998	.0015	.8920	.9916	.0731
.9900	.9998	.0021	.8900	.9914	.0751
.9880	.9997	.0027	.8880	.9912	.0772
.9860	.9996	.0035	.8860	.9909	.0792
.9840	.9995	.0042	.8840	.9907	.0813
.9820	.9994	.0050	.8820	.9904	.0834
.9800	.9993	.0059	.8800	.9902	.0855
.9780	.9992	.0068	.8780	.9900	.0877
.9760	.9991	.0077	.8760	.9897	.0898
.9740	.9990	.0087	.8740	.9895	.0920
.9720	.9989	.0097	.8720	.9892	.0942
.9700	.9988	.0108	.8700	.9890	.0964
.9680	.9986	.0119	.8680	.9887	.0986
.9660	.9985	.0130	.8660	.9885	.1008
.9640	.9984	.0142	.8640	.9882	.1030
.9620	.9982	.0154	.8620	.9879	.1053
.9600	.9981	.0166	.8600	.9877	.1076
.9580	.9979	.0179	.8580	.9874	.1099
.9560	.9978	.0191	.8560	.9872	.1122
.9540	.9976	.0205	.8540	.9869	.1145
.9520	.9975	.0218	.8520	.9866	.1168
.9500	.9973	.0232	.8500	.9864	.1192
.9480	.9972	.0246	.8480	.9861	.1216
.9460	.9970	.0260	.8460	.9858	.1240
.9440	.9968	.0274	.8440	.9856	.1264
.9420	.9967	.0289	.8420	.9853	.1288
.9400	.9965	.0304	.8400	.9850	.1312
.9380	.9963	.0320	.8380	.9847	.1336
.9360	.9961	.0335	.8360	.9845	.1361
.9340	.9960	.0351	.8340	.9842	.1386
.9320	.9958	.0367	.8320	.9839	.1411
.9300	.9956	.0383	.8300	.9836	.1436
.9280	.9954	.0399	.8280	.9833	.1461
.9260	.9952	.0416	.8260	.9830	.1486
.9240	.9950	.0433	.8240	.9827	.1512
.9220	.9948	.0450	.8220	.9825	.1537
.9200	.9946	.0467	.8200	.9822	.1563
.9180	.9944	.0485	.8180	.9819	.1589
.9160	.9942	.0503	.8160	.9816	.1615
.9140	.9940	.0521	.8140	.9813	.1641
.9120	.9938	.0539	.8120	.9810	.1667
.9100	.9936	.0557	.8100	.9807	.1693
.9080	.9934	.0576	.8080	.9804	.1720
.9060	.9932	.0595	.8060	.9801	.1747
.9040	.9930	.0613	.8040	.9798	.1773
.9020	.9927	.0633	.8020	.9795	.1800

SATURATION K=.8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.8000	.9792	.1827	.7000	.9624	.3331
.7980	.9789	.1854	.6980	.9620	.3364
.7960	.9786	.1882	.6960	.9616	.3397
.7940	.9783	.1909	.6940	.9613	.3430
.7920	.9779	.1937	.6920	.9609	.3463
.7900	.9776	.1964	.6900	.9605	.3496
.7880	.9773	.1992	.6880	.9602	.3530
.7860	.9770	.2020	.6860	.9598	.3563
.7840	.9767	.2048	.6840	.9594	.3597
.7820	.9764	.2076	.6820	.9591	.3631
.7800	.9761	.2105	.6800	.9587	.3664
.7780	.9757	.2133	.6780	.9583	.3698
.7760	.9754	.2162	.6760	.9579	.3732
.7740	.9751	.2190	.6740	.9576	.3766
.7720	.9748	.2219	.6720	.9572	.3801
.7700	.9745	.2248	.6700	.9568	.3835
.7680	.9741	.2277	.6680	.9564	.3869
.7660	.9738	.2306	.6660	.9561	.3904
.7640	.9735	.2335	.6640	.9557	.3938
.7620	.9731	.2365	.6620	.9553	.3973
.7600	.9728	.2394	.6600	.9549	.4008
.7580	.9725	.2424	.6580	.9545	.4042
.7560	.9721	.2454	.6560	.9541	.4077
.7540	.9718	.2484	.6540	.9538	.4112
.7520	.9715	.2513	.6520	.9534	.4148
.7500	.9711	.2544	.6500	.9530	.4183
.7480	.9708	.2574	.6480	.9526	.4218
.7460	.9705	.2604	.6460	.9522	.4254
.7440	.9701	.2634	.6440	.9518	.4289
.7420	.9698	.2665	.6420	.9514	.4325
.7400	.9694	.2696	.6400	.9510	.4360
.7380	.9691	.2726	.6380	.9506	.4396
.7360	.9688	.2757	.6360	.9503	.4432
.7340	.9684	.2788	.6340	.9499	.4468
.7320	.9681	.2819	.6320	.9495	.4504
.7300	.9677	.2850	.6300	.9491	.4540
.7280	.9674	.2882	.6280	.9487	.4576
.7260	.9670	.2913	.6260	.9483	.4613
.7240	.9667	.2945	.6240	.9479	.4649
.7220	.9663	.2976	.6220	.9475	.4685
.7200	.9660	.3008	.6200	.9471	.4722
.7180	.9656	.3040	.6180	.9467	.4759
.7160	.9653	.3072	.6160	.9463	.4796
.7140	.9649	.3104	.6140	.9459	.4833
.7120	.9645	.3136	.6120	.9455	.4870
.7100	.9642	.3168	.6100	.9451	.4907
.7080	.9638	.3201	.6080	.9447	.4944
.7060	.9635	.3233	.6060	.9443	.4981
.7040	.9631	.3266	.6040	.9439	.5018
.7020	.9627	.3298	.6020	.9435	.5056

SATURATION K=.8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.6000	.9430	.5093	.5000	.9218	.7073
.5980	.9426	.5131	.4980	.9214	.7114
.5960	.9422	.5168	.4960	.9209	.7156
.5940	.9418	.5206	.4940	.9205	.7198
.5920	.9414	.5244	.4920	.9200	.7240
.5900	.9410	.5282	.4900	.9196	.7281
.5880	.9406	.5320	.4880	.9191	.7323
.5860	.9402	.5358	.4860	.9187	.7365
.5840	.9398	.5396	.4840	.9183	.7408
.5820	.9394	.5434	.4820	.9178	.7450
.5800	.9389	.5473	.4800	.9174	.7492
.5780	.9385	.5511	.4780	.9169	.7534
.5760	.9381	.5550	.4760	.9165	.7577
.5740	.9377	.5588	.4740	.9160	.7619
.5720	.9373	.5627	.4720	.9156	.7662
.5700	.9369	.5666	.4700	.9151	.7704
.5680	.9364	.5705	.4680	.9147	.7747
.5660	.9360	.5743	.4660	.9142	.7790
.5640	.9356	.5782	.4640	.9138	.7833
.5620	.9352	.5822	.4620	.9133	.7876
.5600	.9348	.5861	.4600	.9129	.7919
.5580	.9343	.5900	.4580	.9124	.7962
.5560	.9339	.5939	.4560	.9120	.8005
.5540	.9335	.5979	.4540	.9115	.8048
.5520	.9331	.6018	.4520	.9111	.8091
.5500	.9326	.6058	.4500	.9106	.8135
.5480	.9322	.6097	.4480	.9101	.8178
.5460	.9318	.6137	.4460	.9097	.8222
.5440	.9314	.6177	.4440	.9092	.8265
.5420	.9309	.6217	.4420	.9088	.8309
.5400	.9305	.6257	.4400	.9083	.8353
.5380	.9301	.6297	.4380	.9079	.8396
.5360	.9296	.6337	.4360	.9074	.8440
.5340	.9292	.6377	.4340	.9069	.8484
.5320	.9288	.6418	.4320	.9065	.8528
.5300	.9283	.6458	.4300	.9060	.8572
.5280	.9279	.6498	.4280	.9056	.8616
.5260	.9275	.6539	.4260	.9051	.8660
.5240	.9270	.6579	.4240	.9046	.8705
.5220	.9266	.6620	.4220	.9042	.8749
.5200	.9262	.6661	.4200	.9037	.8793
.5180	.9257	.6702	.4180	.9033	.8838
.5160	.9253	.6743	.4160	.9028	.8882
.5140	.9249	.6784	.4140	.9023	.8927
.5120	.9244	.6825	.4120	.9019	.8972
.5100	.9240	.6866	.4100	.9014	.9016
.5080	.9236	.6907	.4080	.9009	.9061
.5060	.9231	.6948	.4060	.9005	.9106
.5040	.9227	.6990	.4040	.9000	.9151
.5020	.9222	.7031	.4020	.8995	.9196

SATURATION K=.8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.4000	.8991	.9241	.3000	.8752	1.1575
.3980	.8986	.9286	.2980	.8747	1.1624
.3960	.8981	.9331	.2960	.8743	1.1672
.3940	.8977	.9377	.2940	.8738	1.1720
.3920	.8972	.9422	.2920	.8733	1.1769
.3900	.8967	.9467	.2900	.8728	1.1817
.3880	.8963	.9513	.2880	.8723	1.1866
.3860	.8958	.9558	.2860	.8718	1.1914
.3840	.8953	.9604	.2840	.8713	1.1963
.3820	.8949	.9649	.2820	.8708	1.2012
.3800	.8944	.9695	.2800	.8704	1.2060
.3780	.8939	.9741	.2780	.8699	1.2109
.3760	.8934	.9787	.2760	.8694	1.2158
.3740	.8930	.9833	.2740	.8689	1.2207
.3720	.8925	.9879	.2720	.8684	1.2256
.3700	.8920	.9925	.2700	.8679	1.2305
.3680	.8915	.9971	.2680	.8674	1.2354
.3660	.8911	1.0017	.2660	.8669	1.2403
.3640	.8906	1.0063	.2640	.8664	1.2453
.3620	.8901	1.0110	.2620	.8659	1.2502
.3600	.8897	1.0156	.2600	.8655	1.2551
.3580	.8892	1.0202	.2580	.8650	1.2601
.3560	.8887	1.0249	.2560	.8645	1.2650
.3540	.8882	1.0295	.2540	.8640	1.2699
.3520	.8877	1.0342	.2520	.8635	1.2749
.3500	.8873	1.0389	.2500	.8630	1.2799
.3480	.8868	1.0435	.2480	.8625	1.2848
.3460	.8863	1.0482	.2460	.8620	1.2898
.3440	.8858	1.0529	.2440	.8615	1.2948
.3420	.8854	1.0576	.2420	.8610	1.2998
.3400	.8849	1.0623	.2400	.8605	1.3047
.3380	.8844	1.0670	.2380	.8600	1.3097
.3360	.8839	1.0717	.2360	.8595	1.3147
.3340	.8834	1.0764	.2340	.8590	1.3197
.3320	.8830	1.0811	.2320	.8585	1.3248
.3300	.8825	1.0859	.2300	.8580	1.3298
.3280	.8820	1.0906	.2280	.8576	1.3348
.3260	.8815	1.0954	.2260	.8571	1.3398
.3240	.8810	1.1001	.2240	.8566	1.3448
.3220	.8806	1.1049	.2220	.8561	1.3499
.3200	.8801	1.1096	.2200	.8556	1.3549
.3180	.8796	1.1144	.2180	.8551	1.3600
.3160	.8791	1.1192	.2160	.8546	1.3650
.3140	.8786	1.1239	.2140	.8541	1.3701
.3120	.8781	1.1287	.2120	.8536	1.3751
.3100	.8777	1.1335	.2100	.8531	1.3802
.3080	.8772	1.1383	.2080	.8526	1.3853
.3060	.8767	1.1431	.2060	.8521	1.3904
.3040	.8762	1.1479	.2040	.8516	1.3954
.3020	.8757	1.1527	.2020	.8511	1.4005

SATURATION K=.8

R	GD	1/GD(DB)	R	GD	1/GD(DB)
.2000	.8506	1.4056	.1000	.8254	1.6665
.1980	.8501	1.4107	.0980	.8249	1.6718
.1960	.8496	1.4158	.0960	.8244	1.6772
.1940	.8491	1.4209	.0940	.8239	1.6825
.1920	.8486	1.4260	.0920	.8234	1.6878
.1900	.8481	1.4312	.0900	.8229	1.6932
.1880	.8476	1.4363	.0880	.8224	1.6985
.1860	.8471	1.4414	.0860	.8219	1.7039
.1840	.8466	1.4465	.0840	.8214	1.7093
.1820	.8461	1.4517	.0820	.8209	1.7146
.1800	.8456	1.4568	.0800	.8204	1.7200
.1780	.8451	1.4620	.0780	.8198	1.7254
.1760	.8446	1.4671	.0760	.8193	1.7308
.1740	.8441	1.4723	.0740	.8188	1.7362
.1720	.8436	1.4774	.0720	.8183	1.7415
.1700	.8431	1.4826	.0700	.8178	1.7469
.1680	.8426	1.4878	.0680	.8173	1.7523
.1660	.8421	1.4930	.0660	.8168	1.7577
.1640	.8416	1.4982	.0640	.8163	1.7631
.1620	.8411	1.5033	.0620	.8158	1.7686
.1600	.8406	1.5085	.0600	.8153	1.7740
.1580	.8401	1.5137	.0580	.8148	1.7794
.1560	.8396	1.5189	.0560	.8143	1.7848
.1540	.8391	1.5241	.0540	.8137	1.7902
.1520	.8386	1.5294	.0520	.8132	1.7957
.1500	.8381	1.5346	.0500	.8127	1.8011
.1480	.8375	1.5398	.0480	.8122	1.8065
.1460	.8370	1.5450	.0460	.8117	1.8120
.1440	.8365	1.5502	.0440	.8112	1.8174
.1420	.8360	1.5555	.0420	.8107	1.8229
.1400	.8355	1.5607	.0400	.8102	1.8283
.1380	.8350	1.5660	.0380	.8097	1.8338
.1360	.8345	1.5712	.0360	.8092	1.8393
.1340	.8340	1.5765	.0340	.8087	1.8447
.1320	.8335	1.5817	.0320	.8081	1.8502
.1300	.8330	1.5870	.0300	.8076	1.8557
.1280	.8325	1.5923	.0280	.8071	1.8611
.1260	.8320	1.5975	.0260	.8066	1.8666
.1240	.8315	1.6028	.0240	.8061	1.8721
.1220	.8310	1.6081	.0220	.8056	1.8776
.1200	.8305	1.6134	.0200	.8051	1.8831
.1180	.8300	1.6187	.0180	.8046	1.8886
.1160	.8295	1.6240	.0160	.8041	1.8941
.1140	.8290	1.6293	.0140	.8036	1.8996
.1120	.8285	1.6346	.0120	.8031	1.9051
.1100	.8280	1.6399	.0100	.8025	1.9106
.1080	.8274	1.6452	.0080	.8020	1.9161
.1060	.8269	1.6505	.0060	.8015	1.9216
.1040	.8264	1.6558	.0040	.8010	1.9271
.1020	.8259	1.6611	.0020	.8005	1.9327

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Since Kochenburger presented the describing function numerous [illegible] made to improve and/or simplify [illegible] methods of studying non-linearities in servo-mechanisms. This paper reviews some of the most common methods of describing function development. (U)

The describing function has been used primarily for stability analysis on the Nichols, polar, and Nyquist plots. This paper shows the use of the real and imaginary components of the describing function on the parameter plane. In addition a generalized digital computer program is developed for generating describing function data for a large class of nonlinearities. Data is computed and tabulated for a number of common nonlinearities, and these tables are included in an appendix. (U)

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